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Effects of Illustrations on Retention and Visual Attention Using Authentic Textbooks

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ABSTRACT

EFFECTS OF ILLUSTRATIONS ON RETENTION AND VISUAL ATTENTION USING AUTHENTIC TEXTBOOKS

by

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ABSTRACT OF GRADUATE STUDENT RESEARCH

Thesis

Andrews University

School of Education

Title: EFFECTS OF ILLUSTRATIONS ON RETENTION AND VISUAL ATTENTION USING AUTHENTIC TEXTBOOKS

Name of researcher: Loris P. Fagioli

Name and degree of faculty chair: Rudolph Bailey, Ph.D.

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Problem

The purpose of this exploratory study was to validate a model of multimedia learning, incorporating learner-specific characteristics such as intelligence, memory, and measures of visual attention.

Method

The sample consisted of 62 Andrews University students (26 males, 36 females, and mean age 21.7). Data were gathered by means of standardized testing (RPM, WAIS-III) and eye-tracking. MLR was used to determine significant visual attention predictors for retention and SEM was used to test a hypothesized model of multimedia learning.

Results

Multiple Linear Regression was significant ($p<.05$); however, only one variable was a significant contributor ($p<.05$). Structural Equation Modeling indices were good ($\chi2>.05$; GFI = .923; CFI = .986; RMSEA = .043; PGFI = .451) proving the hypothesized model's excellent fit to the data.

Conclusions

This exploratory study indicates that there are different learning strategies in a college population that are not related to characteristics such as intelligence or working memory. These strategies are learned or acquired and have thus clear implications for practice.

Andrews University

School of Education

EFFECTS OF ILLUSTRATIONS ON RETENTION AND VISUAL ATTENTION USING AUTHENTIC TEXTBOOKS

A Thesis

Presented in Partial Fulfillment

of the Requirements for the Degree

Master of Arts

by

Loris P. Fagioli

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LIST OF ABBREVIATIONS

CLT	Cognitive Load Theory
CTML	Cognitive Theory of Multimedia Learning
DCT	Dual Coding Theory
ITPC	Integrated Model of Text and Picture Comprehension
LTM	Long-Term Memory
LTWM	Long-Term Working Memory
MLR	Multiple Linear Regression
SEM	Structural Equation Modeling
SR	Sensory Register
STM	Short-Term Memory
WM	Working Memory

CHAPTER 1

INTRODUCTION

> *If fish were to become scientists, the last thing they might discover would be water. Similarly, researchers have too often failed to investigate important aspects of their environment because being immersed in it, they fail to notice certain components of it; or, having noticed a component, they simply assume that it must be that way. One such example from reading is the ubiquitous use of illustrations in books.*
>
> ~S.J. Samuels

During the past decades, illustrations and pictures have become an essential part of textbooks and the most important media to communicate scientific information (Mayer & Gallini, 1990). Technology has also expanded and improved, leading to the use of colored pictures, better resolution, photographs, animations, video, internet, etc., in instruction. All these advances have changed instructional strategies of educators and have changed the context and use of materials and textbooks in the classroom. These changes and new technologies have also piqued the interest of many researchers who started investigating this new field of multimedia learning. The following chapters will outline prevalent research findings in this field, mention limitations and implications for much needed future research, as well as present and discuss a study with a new approach and interesting findings. This exploratory study is built on a theoretical foundation and continues in line with previously published research, trying to better understand the processes that are involved in learning with textbooks. The first chapter gives a short overview of the study. Chapter 2 takes an in-depth look at the existing literature on multimedia learning, and the chapter 3 defines the methods and instruments that were applied in this research. Chapter 4 presents the results, and chapter 5 interprets results, discusses the implications, and gives recommendations for future research.

Statement of the Problem

It has been assumed in the field of education that illustrations improve comprehension and learning and increase motivation. However, research has only recently been interested in analyzing these assumptions and it was not until the 1970s (Houghton & Willows, 1987) that articles were published more regularly on the topic of what now is known as multimedia learning. There is a consensus in literature that good illustrations used in the right context do facilitate learning (e.g., Levin, Anglin, & Carney, 1987; Carney & Levin, 2002; Levie & Lentz, 1982; see chapter 2). However, the topic has proven to be quite intricate and complex. "More recently, research has concentrated on disentangling the relevant conditions needed to obtain illustration benefits in learning and the underlying reasons for these beneficial effects" (Hannus & Hyönä, 1999, p. 97). Especially questions of who benefits most from illustrations are less well researched. Research on learner characteristics and learning strategies is not abundant; however, in order to increase efficiency and quality of teaching and school practices these questions need to be addressed in empirical investigations.

This study is an exploratory study that tested a proposed model (Figure 4) of factors involved in learning with illustrated texts. The model is based on the prevalent cognitive theories and will be applied in an authentic environment. State-of-the-art eye-tracking was used in order to record visual attention during the studying of the textbooks and was correlated with students' analytic intelligence and working memory. Multiple Linear Regression (MLR) and Structural Equation Modeling (SEM) were used to determine relevant variables and test the hypothesized model.

The following gives a more detailed view of the research questions and purpose that guided this study, as well as show how this research is significant and important.

Research Question

This exploratory study was guided by the following research questions:

1. Which eye-tracking variables are significant contributors in predicting retention outcomes? Based on the outcome of this question the variable(s) will be incorporated into a hypothesized model (Figure 4).

2. Will the hypothesized model be a good fit with the data?

3. Can the hypothesized model be modified on the basis of the data in order to achieve a better fit?

Purpose of the Study

This exploratory study is one of a few, linking basic research with application to education. This study tries to understand the effects of cognitive ability and working memory on processing illustrated texts and is interested in the analysis of a subject's direction of visual attention while reading. Consequently the study is trying to understand what makes successful and unsuccessful learning with textbooks.

Furthermore, Structural Equation Modeling (SEM) is a relatively new statistical instrument that makes a holistic approach to research possible. Human phenomena can be measured at the same time and in a multivariate setting, which is a significant advantage over univariate research, which is often limited to the laboratory setting and not entirely transferable to real-life settings. This research tested for significant eye-tracking variables that are predictors of overall retention. These variables are incorporated into a hypothesized model of multimedia learning. The fit of the proposed model was tested in an initial step with SEM and subsequent steps assessed whether the model could be improved.

In sum, the purpose of this exploratory study was to propose and validate a holistic model of learning with illustrated texts, by means of state-of-the-art statistical analysis and eye-tracking. This study thus contributes to the field of education and multimedia learning with its new and original approach.

Importance and Significance

This study takes established principles of multimedia learning (Mayer, 2005a; see chapter 2) and applies them into an authentic situation, thus making this study an ideal foundation for implications in an educational context. As studying textbooks is an essential part of education, the findings will be beneficial for educators and can improve instruction and success in learning. This research will also contribute to the existing theory of multimedia learning and will create a basis for future research especially in terms of data references for eye-tracking and SEM.

Limitations and Delimitations

The following are the limitations of the study:

1. Sample selection: The selection of the subjects was not random, but based on voluntary participation.

2. Sample size: Because of money and time restraints the sample size was limited to only 62 subjects, which has been shown to limit SEM analysis (Meyers, Gamst, & Guarino, 2006).

3. Research design: No conclusions of cause and effect are warranted from this research, since the design is correlational in nature.

The following are the delimitations of the study:

1. From the broad field of multimedia learning, static illustrations and non-verbal text were selected. Animation, internet, video, etc., are not covered in this study. The focus is only on textbook material.

2. The passages are selected from physiological psychology textbooks. Biology is a field in which illustrations are a major component and most research in the field is on the topic sciences (e.g., Hannus & Hyönä, 1999; Levie & Lentz, 1982).

3. Only retention of learned material was tested and not transfer and application of knowledge.

Definition of Terms

Multimedia: The simultaneous presentation of words (spoken or written) and picture (illustrations, photos, animations, videos) (Mayer, 2005a).

Working Memory: A theoretical construct in cognitive psychology that provides temporary storage for important functions such as language comprehension, learning, and reasoning (Baddeley, 1992).

Analytic intelligence: The ability to form perceptual relations and independent analogies, and solve problems involving new information without relying extensively on previous knowledge (Carpenter, Just, & Shell, 1990).

Visual attention: The voluntary and sustained attention to a particular place in the visual field (Steinman & Steinman, 1998).

CHAPTER 2

LITERATURE REVIEW

This chapter presents a broad overview on the current status of the research on multimedia learning. Multimedia is defined as the simultaneous presentation of words (spoken or written) and pictures (illustrations, photos, animations, videos) (Mayer, 2005a). During the past decades, illustrations and pictures have become an essential part of textbooks and the most important media to communicate scientific information (Mayer & Gallini, 1990). Technology has expanded and improved, leading to the use of colored pictures, better resolution, photographs, animations, video, internet, etc., in instruction. What originally started as an interest in only printed text and illustrations today encompasses other material as well. The evolution of computers, internet, and technology has expanded everything from the scope of research to the effectiveness and the cognitive processes that are involved in what is now called multimedia learning.

After a short introduction and historical reflections on the topic, this chapter contains four sections. The first is a summary of theories of multimedia learning and the cognitive processes involved in multimedia learning. The section will mostly be based on secondary literature, in order to give a comprehensive overview. The other three parts, nature of materials, learner characteristics, and principles of multimedia learning, are mainly based on primary research and have been selected out of an abundance of articles, with the following criteria: Only studies using static, non-verbal text and illustrations were selected. Other research findings on audio, animation, video, internet, etc., are not covered in detail.

Introduction and Historical Reflections

Illustrations have been an integral part of communication for thousands of years. Drawings from aborigines in Australia, elaborate cave drawings in France and Spain, and hieroglyphs of the ancient Egyptians are only a few examples of the role illustrations have played in human history. More recently, illustrations have been part of story-telling in children's story books and in instruction with textbooks. The tradition of using more than one medium in textbooks can be traced back several hundred years to Comenius who published his pioneer work *Orbis Sensualium Pictus* (The world explained in pictures) in 1658 where he emphasizes the importance of adding pictures to text.

The phenomenon of adding illustrations in textbooks became more and more prevalent with the advances of technology. In 1987, Evans, Watson, and Willows investigated over 60 textbooks across all grade levels (Grades 1-12) and found that, on average, illustrations were present in over 50% of all pages. Elementary textbooks showed pictures on almost all of the pages, whereas Grades 7 to 12 contained illustrations on 30 to 60% of all pages. In a similar study by Woodward (1993), seven secondary school textbooks showed between 14 and 26% illustrated pages. Both studies show that on average 50% of an illustrated page was devoted to the actual illustration; however, the percentage decreases with higher grade levels. The large amount of space dedicated to illustrations as well as the prevalence of pictorial adjuncts in textbooks justifies questions on the reasons for illustrating texts. Evans et al. (1987) interviewed nine major publishers on the factors that guide the process of illustrating a textbook. Their results show that the publisher, editor, and art director are mainly responsible for the illustrations and that the author indicates only which passages should be illustrated. The author however is rarely involved in the design process. The designer is primarily responsible for the decision of how many and what types of illustrations are chosen. Book content, aesthetics, and targeted audience were reported to be guiding factors. More disturbingly, however, is that the designers were mostly self-taught and did not attend any courses on book design. More importantly, all publishers stated that consulting research played little if any role in their decision-making process. Houghton and Willows (1987) agree with many other researchers that "at present, it would appear that a great deal in instructional text design is guided by intuition, prior practice, trial and error approaches, and marketability considerations" (p. iii). It seems that research does not have any influence on textbook design. But what is the research saying about illustrations and their instructional value? The following is a short overview of reviews on pictorial adjuncts to text.

One would assume with the vital role illustrations have played in the last centuries and millennia that a wide variety of research has been published on the topic. It is thus interesting to note that despite the widespread use of illustrations, little research was done until the 1970s (Houghton & Willows, 1987). Samuels (1970) begins his review of the few studies on the effects of illustrations that were done before the 1970s with the following words:

> If fish were to become scientists, the last thing they might discover would be water. Similarly, researchers have too often failed to investigate important aspects of their environment.... One such example from reading is the ubiquitous use of illustrations in books for beginning reading instructions. (p. 397)

Another interesting detail in the history of multimedia research concerns the results of the Samuels study. In his review of the few available studies he concludes that illustrations interfere with learning and do not facilitate comprehension! These findings have not gone unchallenged with several authors (for reviews see, e.g., Carney & Levin, 2002; Levie & Lentz, 1982) publishing results with positive effects of illustrations. More recent research suggests that these early negative effects of illustrations can be explained by issues of definition and methodology (Levin et al., 1987; Peeck, 1987; for a review on responses to Samuels's study see Lemonnier-Schallert, 1980).

After the 1970s, a plethora of research was published in order to find an answer to the question, Do illustrations facilitate learning? In their excellent review of the effects of text illustrations, Levie and Lentz (1982) reviewed 55 studies of the 1970s. The authors report that 85% of the studies found a significant difference in learning outcomes between non-illustrated text and illustrated text. Illustrations facilitated learning and showed an average improvement of 36%. No effects were found on learning outcomes on those parts in the text that were not related to the picture. The effects of the pictures are thus specific to the information shown in the illustration.

Two other excellent reviews of the literature of the 1980s and 1990s will be mentioned here. Levin and colleagues (Carney & Levin, 2002; Levin et al., 1987) reviewed most of the research in the past two decades and confirm the results of Levie and Lentz. A medium effect size of .71 is reported for illustrated texts when compared to non-illustrated texts.

The research over the past decades has supported the assumption that good and carefully chosen pictures do facilitate learning. It soon became apparent, however, that the question of whether illustrations facilitate learning was too broad and needed refinement. There are several pictorial adjuncts (charts, graphs, pictures, etc.), several purposes of illustrations (attentional, affective, cognitive, etc.), functions of illustrations (decorational, representational, organizational, interpretational, and transformational), as well as different types of presentation (static or oral text, static or moving pictures). The question of whether illustrations facilitate learning is not appropriate, but rather the question should be, Under which condition are illustrations most effective? (Holliday, 1975). A more systematic approach is needed in order to find answers to the 'why', 'how', 'what', 'when', and 'for whom' illustrations work (Carney & Levin, 2002; Gyselinck & Tardieu, 1999; Mayer, 2005a). The following sections will review the literature on these questions. The first section on the theoretical models of multimedia learning will look at the 'how's' (How does it work?). The section on the nature of materials will be concerned with the 'whys' 'whens' and whats' (When do illustrations enhance learning? and What kind of illustrations facilitate learning?). Learner characteristics will deal with the 'for whoms' (Who benefits most) and principles of multimedia learning with the 'whens' and 'wheres' (When should illustration be used? and Where can we apply the theory?).

Theoretical Foundations

In the last 10 years, multimedia learning has been the target of much research and has emerged as a discipline (Mayer, 2005a). It was mentioned in the introduction that researchers were slow to be interested in the effects of illustrations on learning, even though pictures have been used in instruction for centuries. After the 1970s researchers started investigating this topic more thoroughly. Despite the increased interest, a theoretical background was missing. Mayer and Anderson (1992) wrote in the early 90s that a research-based theory was lacking. During the last two decades several theories have been proposed and the following will present the theories that are most discussed and cited in multimedia research. This section will thus try to give answers to the question of how human cognition works and how pictures facilitate learning.

The following sections will present the most prevalent theories of multimedia learning: Cognitive Load Theory, Dual Coding Theory, Cognitive Theory of Multimedia Learning, and the Integrated Model of Text and Picture Comprehension. A more extensive review and an excellent presentation and summary of these theories can be found in Mayer (2005a). However, since all these theories are based on components and processes concerned with memory, a short summary of the relevant cognitive processes involved in learning will first be presented.

Relevant Cognitive Processes

Learning involves selecting, acquiring, and storing information. The following will look at the processes involved in retaining and storing the information in memory as well as look at the selection of information via visual attention.

Memory

During the 1960s there was much controversy on how to regard human memory. A unitary model and models with two or more subsystems were proposed. Studies on brain-damaged patients and results from other studies soon supported the abandonment of the unitary model (Baddeley, 1992). Since then, a model of human memory has been proposed, consisting of three parts: long-term memory (LTM), short-term memory (STM), and the sensory register (Shiffrin & Atkinson, 1969). LTM is a memory bank with unlimited capacity and no decay in memory. LTM's capacity is in stark contrast to STM and the sensory register, where the latter two store information only for a very short time. The sensory register stores information only for a few milliseconds before being transferred to the STM (Shiffrin & Atkinson, 1969). STM is able to hold information only for a limited time and is seen in contrast to LTM. STM can store about 7 ± 2 chunks of information for about 20 seconds, and process about 2 to 4 chunks at the same time (Shiffrin & Atkinson, 1969; Sweller, van Merrienboer, & Paas, 1998). It is important to notice that these limitations refer only to novel situations and information. Information stored in LTM can easily be accessed and can enhance the efficacy of processing information (see long-term working memory below). Further research has shown that STM is not only storing information, but is also fundamental in learning, retrieving information, and other cognitive processes (Baddeley, 1992). Some researchers thought the term *working memory* (WM) was more adequate to the new findings and it is now widely used, especially in psychometric testing and research on learning (Baddeley, 1992; Neath, Brown, Poirier, & Fortin, 1999). The difference between STM and WM is not clearly defined, nevertheless the two concepts seem to address different aspects of memory. The distinction between STM and WM can be seen as follows: The theory of STM emphasizes mnemonic aspects and processes of remembering in simple tasks and is seen in distinction with LTM, while the theory of WM focuses more on the attentional role and processes of memory in more complex situations (Ericsson & Kintsch, 1995; see Neath et al., 1999, for a detailed comparison between STM and WM).

Baddeley (1992) distinguishes working memory into a central executive and two slave systems: the visual-spatial scratch-pad and the phonological loop. These two subsystems are controlled by the central executive. Baddeley's research with Alzheimer patients showed some support for the central executive's function of coordinating the two subsystems. While the hypothesis of a central executive has been difficult to prove, a lot of research has been done on the two subsystems (e.g., Paivio & Clark, 1986). The phonological loop stores acoustic or speech-based information, whereas the visual-spatial sketch-pad stores visual images. These two systems will be discussed in further detail in association with the dual coding theory.

In order to perform complex cognitive tasks such as mental calculations, or generating mental models without the presence of pictures requires access to a large amount of information. Research on mental calculations or experienced chess players has shown limits to the concept of working memory. Learning new information in familiar situations and well-known domains does not show the same limitations that were known of STM or WM. Given the fact that WM is severely limited, phenomena of greatly expanded working memory for skilled performers or instances where an interruption in task did not show an effect on performance demanded new explanations. Ericsson and Kintsch (1995) have suggested that WM can be divided into short-term working memory and long-term working memory (LTWM). LTWM is an expert skill, where the subject is not limited by the usual constraints of working memory. However, LTWM is only of use in an expert domain and cannot be used in a non-expert context. LTWM helps retrieving and relating information stored in LTM, and can be learned through practice. This can be seen with mathematically talented individuals, who are able to perform complex calculations and are able to recall series of numbers exceeding the normal span multiple times; or with chess masters who can play chess games without being able to manipulate a board. Text comprehension can be seen as an example where most adults in our society make use of their LTWM skill (Kintsch, Patel, & Ericsson, 1999). LTWM is needed in order to comprehend and read texts in an economical way.

The theory of LTWM has not gone unchallenged. Instead of proposing a qualitatively different processor, the limitations of memory can be seen as a continuum (Sweller, 2005a). At the one end, WM limitations are severe when dealing with novel information. The limitations become less and less relevant until, at the other end of the continuum, dealing with familiar information shows no limitations.

Nevertheless, it is agreed upon that working memory plays an important factor in information processing and more specifically in multimedia contexts (Just & Carpenter, 1992; Kaakinen, Hyönä, & Keenan, 2003).

Visual Attention

The previous section gave a short summary on the cognitive structures that are involved when processing information. Preceding the processing, however, selecting the information to be processed is equally important. The direction of attention has also been investigated and given much attention. Research has looked into the processes of top-down (attention is directed by a goal) or bottom-up (attention is captured by an object or stimulus) attentional control. Research indicates that top-down and bottom-up modes are interacting (Egeth & Yantis, 1997). Any perceptual act requires an attentional control element. Visual cues that are relevant to the subject's goal (in everyday life, or through given instructions) will influence direction attention. Thus, distribution of attention relies equally on visual stimuli and on the goals or plans of the individual. Attentional direction is also of importance in a multimedia setting. The observer is influenced both by top-down (goal of learning and studying the material) as well as bottom-up (the visual stimuli presented in a textbook) processes (Egeth & Yantis, 1997).

Visual attention would a priori seem not to be difficult to define. James's (1890) much-cited earliest definition assumed: "Everyone knows what attention is. It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought" (p. 403). Nevertheless, after several disciplines investigated attention, no unitary definition was agreed upon and definitions are conflicting and confusing. Steinman and Steinman (1998) reviewed models of visual attention and proposed a definition containing two parts. "The first mechanism is a conscious or cognitive mechanism that focuses visual attention upon a particular location in the visual field" (p. 148). It is a voluntary process since the individual 'chooses' to look or pay attention to an object which is an example of a top-down process. "The second mechanism of visual attention is stimulus-induced or transient attention. This is an involuntary attentional response to any sudden change or novel stimulus in the visual field" (p. 148). This process is an example of a bottom-up process where a stimulus (e.g., red brake lights in the car ahead) 'captures' the attention and is thus not voluntary but transient or reflexive. In the present study the definition of attention only entails the first part, since the experiment was conducted in a controlled environment with little distractions and the use of only static illustrations and texts. Furthermore, the difficulty of measuring bottom-up processes and the assumed little importance of bottom-up processes in this research explain the exclusion of the second part of the definition for this research.

But how can visual attention be measured? The most obvious solution is to assess where the eye is looking. The interest of measuring visual attention by studying eye movements can be traced back to the late 1870s (for a more detailed history on eye-tracking see Jacob & Karn, 2003). Early studies were extremely complex or invasive (mechanical contact with the eye). With the advent of the computer and other technological advances, tracking eye movements has been made a lot easier and affordable, and recently, application of eye-tracking in various fields has seen a veritable proliferation (Gale, 2003). Several issues still remain. Until today the question of whether the observer's gaze can be equaled to his or her visual attention is inconclusive (Gale, 2003). We can move attention without moving the eyes. However, it has been suggested that in complex situations visual attention is highly correlated with the individual's gaze (Rayner, 1998). Reading and studying illustrations is considered to be a complex situation where locus of attention and eye location are linked and there is no strong foundation to assume otherwise (He & Kowler, 1992). For a review on current research on eye-tracking, see Radach, Hyönä, and Deubel (2003) and Rayner (1998).

The cognitive architecture and concepts of visual attention are essential to learning situations and have been briefly discussed. Subsequently, processes and theories pertaining to learning and more specifically to learning in a multimedia environment will be discussed. The following is a short overview of the most common theories on multimedia learning that have evolved during the past decades and have established themselves in the field. Many of them are overlapping and similar but have a different focus or approach to the processes involved in learning.

Dual Coding Theory

It was previously mentioned that in the early stages of research on human cognition, working memory was seen as a singular entity. The research by Baddeley (1992) has given indication of a separation of WM. Dual Coding Theory (DCT) is another line of research that reports two distinct verbal and nonverbal systems (Paivio, 1986). DCT was initially based on research of the 60s and 70s and several revisions were made to the theory. However, the basic structures were retained in all versions. For a review of DCT see Paivio (1991). The basic structures of DCT are the verbal and visual systems. While the verbal system encompasses information conveyed in written, spoken, or tactual (e.g., Braille) words, the visual or nonverbal system carries information from visual objects, sounds, or the manipulation of objects. These two systems can work independently but there can be cueing from one system to the other which helps to interpret processed information. Furthermore, one system can activate another. This process is evident in the ability to produce a mental picture when reading or hearing a word, or in the ability to name objects when seeing them.

DCT has proven to have several implications for education and has been used to explain diverse psychological phenomena. For instance, DCT can explain limitations in learning and how to overcome them. Verbal information needs to be processed and organized sequentially, and cannot be processed simultaneously (e.g., listen to words and read a text). Nonverbal information, however, can be processed or activated simultaneously (e.g., manipulating objects and reacting to noises). For education the following hypothesis is of vital importance. DCT suggests that the availability of both systems increases the probability of retrieving information. That is, if information can be processed in both systems simultaneously (seeing a picture and hearing words) information is learned more deeply and easily. The synchronous quality of visual information offers multiple units to be present at the same time which makes relevant information available for processing and which increases probability of successful learning (Paivio & Clark, 1986). This quantitative reasoning (the same information is presented twice thus learned better) is a valid but incomplete argument. There seems to be a different qualitative element as well. Illustrations and text enhance each other because they entail qualitatively different information and readers who successfully integrate the two and build connections show greater benefits (Mayer, 2005b).

Clark and Paivio (1991) stress the importance of DCT as a unifying and integrative theory. DCT encompasses cognitive, affective, and sensorimotor principles. DCT is a widely accepted theory and many research studies have used the theory to explain findings. However, DCT has also received considerable criticism. A major criticism concerns the hypothesis that the combination of picture and text is always superior to an isolated picture or text, thus neglecting possible negative effects of illustrated text (Schnotz & Bannert, 2003). The theory is thus limited to explaining positive effects and does not offer help in explaining negative effects of pictures (e.g., negative results by Samuels, 1970). Furthermore, the process of simply adding two channels in order to achieve better outcome ignores the active processes involved (Schnotz, Bannert, & Seufert, 2002).

Alternative and more comprehensive theories have been suggested, which will be outlined briefly in the following paragraphs. Nevertheless, DCT has proven to be useful in explaining various phenomena and is an integral part in all of the following theories and is cited in most research concerning multimedia learning.

Cognitive Load Theory

Sweller and Chandler (1994) have developed the cognitive load theory based on much empirical analysis. The theory is based on the cognitive structures mentioned above but focuses more on applications and implications for educational practices. Learning new material involves storing information in schemas. Before storing, information is processed by working memory which is severely limited in capacity. Information in working memory is processed in two channels depending on the nature of the information (visual or auditory). In authentic learning situations, however, information is often extensive and can be structured so that the individual is forced to process information simultaneously. While the cognitive limitations are to a certain degree innate in all humans, the material to be learned or the method with which they are taught can be modified and can facilitate or obstruct learning. Cognitive load theory (CLT) discusses extraneous, intrinsic, and germane cognitive loads that are imposed by the format of instruction or the chosen set-up of the environment (Sweller et al., 1998). Intrinsic load addresses the natural complexity of a subject, which can be either low or high depending on the subject or material. While intrinsic load cannot be altered, extraneous cognitive load is artificially produced by the mode of instruction or presentation. Lastly, germane cognitive load is produced by the act of learning and scheme construction (Sweller, 2005a).

By understanding the principles of CLT, educational environments can be improved. In particular the theory has implications for multimedia learning, as the choice of instructional material and method should take into account the limitations of working memory and the different loadings of the presented material. Effective learning can take place only if the sum of the intrinsic, extraneous, and germane cognitive loads does not exceed the capacity of working memory (Sweller, 2005a; Sweller & Chandler, 1994).

While the theory can be helpful to understand processes, one major question lies in the ability to measure cognitive load. Most studies concerned with multimedia learning make references to CLT when explaining their results (Chandler & Sweller, 1991); however, this assumption is generally not tested empirically. Brünken, Steinbacher, Plass, and Leutner (2002) developed a new and promising approach in measuring cognitive load directly. In their experiment with college students, the participants studied materials (primary task) but were presented simultaneously with a secondary task. Since working memory is limited, the secondary task should be sensitive to changes in cognitive load. Their results show that the method of dual tasks is indeed a promising and valuable strategy for measuring cognitive load. The dual-task methodology should be applied in more research when trying to assess cognitive load as more research is needed to bolster the findings of differences in visual learning and also in auditory learning.

While CLT is a practical and important theory in learning and several principles of multimedia learning (see below) use CLT to explain the effects, many of its findings are limited by assumptions and indirectly measured outcomes. Evidence that cognitive loads can be measured has been proposed (Brünken et al., 2002) but questions still remain on methodology of measuring cognitive load (Mayer, 2005b) and more research is needed in that area.

CLT is a theory concerned with learning environments. However, there is no specific reference to multimedia settings such as text and picture layouts. While useful to explain overload of working memory and thus inference with learning, CLT does not lend itself as a comprehensive multimedia theory. The following two theories are the only two comprehensive theories that explain the relevant cognitive processes involved.

Cognitive Theory of Multimedia Learning

In their review of the literature preceding the 1980s, Levie and Lentz (1982) came to the following conclusion: "That illustrations *can* facilitate learning from text is clear. *How* they do so is not clear" (p. 224). Even 10 years later Mayer and Anderson (1992) noted that a theory on multimedia learning was lacking. Since then, Richard E. Mayer has been one of the most cited authors and is a well-respected expert in the field. He has worked on a theory of multimedia learning over the past decades and has continually improved and refined the Cognitive Theory of Multimedia Learning (Mayer, Steinhoff, Bower, & Mars, 1995; Mayer, 2002, 2005b).

Cognitive Theory of Multimedia Learning (CTML) is based on the dual coding theory as well as on the cognitive load theory. The theory is consistent with research on cognition and focuses on applicability to education and practice. CTML incorporates the three memory stores (LTM, WM, SR) and is based on three assumptions. First, information is processed in different channels (dual coding). Second, these channels have a limited capacity (cognitive load theory, working memory), and third, learning involves active processing (Mayer, 2002). Generating a combined mental picture through organizing, making sense, and attention direction is an active process that is guided by a central executive and prior knowledge stored in LTM (Mayer, 2005b).

Figure 1 shows two evident structures. First, learning involves all memory stores (SR, WM, LTM), and is channeled by two systems (visual and auditory). Furthermore, several processes take place for information to be learned. First, as already mentioned, selecting information is essential. Selecting words and selecting images are the first two steps. The learner pays attention to relevant words or pictures and transfers sounds or images into working memory. Thereafter words are organized into a verbal model, whereas images are organized into a pictorial model. The learner builds connections among the selected words or images to create the two models. The final process is the most important, where the two models and previous knowledge are integrated to form one integrated model (Mayer & Anderson, 1992; Mayer, 2005b). This last step involves a lot of cognitive capacity and is still bound by the limitations of working memory. The whole process of incorporating information into LTM is not done at once but rather over and over again while studying the same text. It is not selecting relevant material and then making a model, but while reading and listening continually updating, integrating, and relating the model to previous knowledge (Mayer, 2005b).

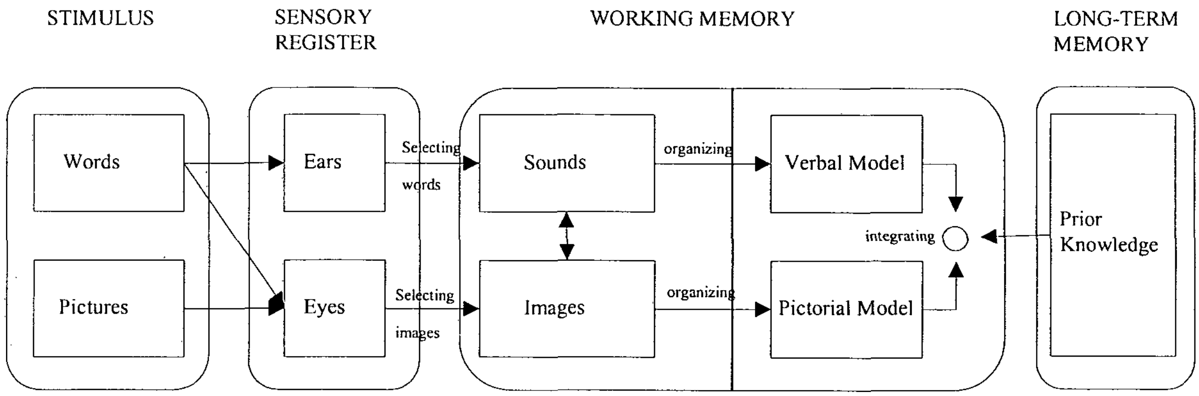


Figure 1. Cognitive theory of multimedia learning. From "Cognitive Theory of Multimedia Learning" (p. 37), by R. E. Mayer, in R. E. Mayer (Ed.), *The Cambridge Handbook of Multimedia Learning*, 2005, New York: Cambridge University Press.

CTML is able explain the processes involved when studying pictures, or spoken or printed words. The following will briefly outline the sequences based on Figure 1. The sequence of processing pictures would be as follows: pictures–eyes–selecting images–images in working memory–organizing images–creating pictorial model–integrating pictorial model with prior knowledge. The processing of spoken words takes another channel. Words–ears–selecting words–sounds in working memory–organizing words--forming verbal model–integrating verbal model with prior knowledge. Processing printed words makes use of both channels: words–eyes--selecting images–images in working memory–transferring images to sounds--organizing words into verbal model–integrating verbal model with prior knowledge. This last example can explain why printed text combined with images is not as effective as images combined with aural words. The former uses the same channel for processing and thus creates more cognitive load than the latter where both channels are used (see modality principle below for further explanation).

The CTML theory has continually been modified over the past 20 years. For instance, earlier versions did not incorporate specific relations to working memory or long-term memory (e.g., Mayer, 1997). Furthermore, previous models used different names (e.g., model of meaningful learning, dual-coding model, generative theory, etc.; see Mayer 2005b). The three principles (dual coding, limited capacity, active processing), however, remained the same. While these improvements are necessary and good, it makes comparisons difficult, especially with the theory presented next. CTML and the integrated model of text and picture comprehension have many similarities, and finding differences is short lived since both theories are being modified continually. In order to address limitations and to critique and compare these two major theories, a separate section addresses these topics below.

Integrated Model of Text and Picture Comprehension

The Integrated Model of Text and Picture Comprehension (ITPC) was proposed by Schnotz and Bannert (2003). It is based on the following assumptions of dual channels (auditive and visual), cognitive architecture (SR, WM, LTM), limited capacity of WM, and active processing. ITPC offers a new interpretation and theoretical background to the commonly used Dual Coding Theory and is an alternative to CTML. Two basic forms of representations are distinguished. There are descriptive representations such as texts, formulas, or mathematical equations. Descriptive representations can be pictures, photographs, drawings, paintings, maps, models, graphs, or other icons. Descriptive representations can express abstract knowledge, whereas depictive can show informational completeness (information on many variables) (Schnotz, 2005). However, representational format does not mean sensory modality. Text can be read or heard or even touched (blind people). Speaking is usually hearing but can also be seen (reading lips).

Figure 2 shows the process from the external representation to the construction of a mental model. It can be seen that the information in the auditive channel will eventually be trans-coded into a depictive mental model. According to this hypothesis the descriptive or auditive channel (top) and the depictive or visual channel (bottom) are only separated during the first processing steps but will later intertwine, so that all external stimuli are processed into a depictive mental model. This process will now be explained in more detail and examples of spoken or written words and sound or visual images will be discussed.

According to the integrated model, the reader is confronted with an external stimulus that is processed by two different channels. A written text enters the visual channel through the visual register and is further processed in visual working memory. The verbal information is sent to the auditive channel and propositional representations are formed which in turn construct a mental model. As an example, the word "table" is read by the eyes and this stimulus is processed for verbal information. Then the concept "table" is activated from LTM and integrated in a mental model with the rest of the sentence or text. In listening to spoken text, the sounds enter the sensory register through the ear and are further processed in auditive working memory. The sounds are analyzed (e.g., distinguishing the sound "table") for verbal information by semantic processing and a propositional representation of "table" is created and produced by LTM and finally a visual mental model of a "table" is generated. A visual image (e.g., seeing a table) enters visual working memory through the eyes. A filter selects pictorial information by thematic selection and a mental model is created and compared with LTM. As a last example the process of auditory pictures is explained. Hearing a car, a bird's call, or the sounds of a familiar voice enter the working memory through the ear and are processed for visual information, which results in the elaboration of a mental model of a car, bird, or person (see Schnotz, 2005, for a more detailed description of these processes).

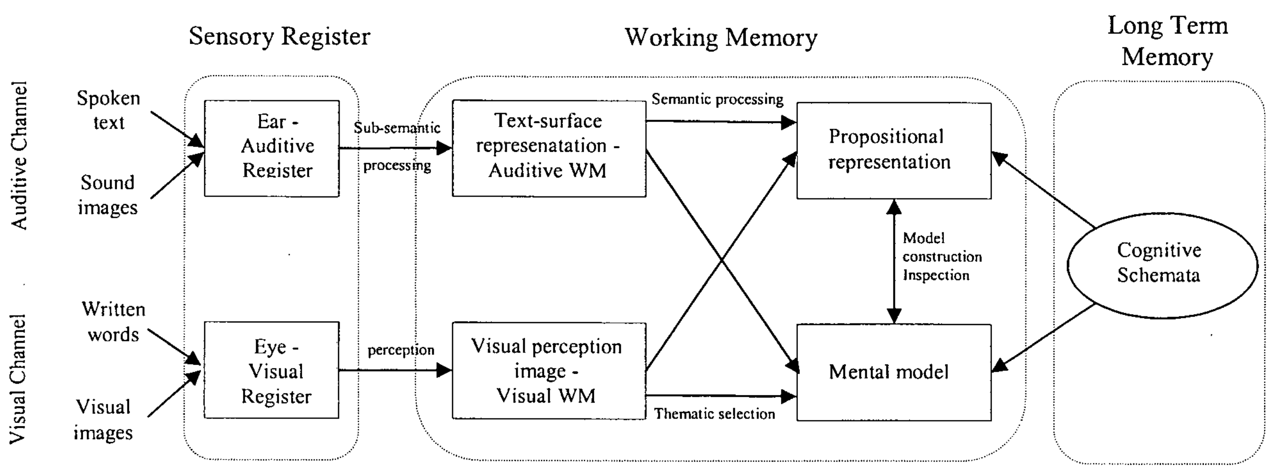


Figure 2. Integrated model of text and picture comprehension. From "Construction and Interference in Learning From Multiple Representation," by W. Schnotz and M. Bannert, 2003, *Learning and Instruction*, *13*, p. 142; and "An Integrated Model of Text and Picture Comprehension" (p. 52), by W. Schnotz, in R. E. Mayer (Ed.), *The Cambridge Handbook of Multimedia Learning,* 2005, New York: Cambridge University Press.

Since the cognitive theory of multimedia learning (Mayer, 2002, 2005b) and the integrated model of text and picture comprehension (Schnotz & Bannert, 2003; Schnotz, 2005) show many similarities and are based on comparable assumptions, several questions arise. What are the strengths and weaknesses of the two models? What are the differences? These and other questions will be addressed in the next section.

CTML and IPTC--Comparison and Critique

CTML and IPTC are theories of multimedia learning that have been missing in the field for many years (Mayer & Anderson, 1992). Thus both theories have helped to better understand the processes involved in multimedia learning and have generated a variety of research findings. Articles published in the last two decades have made more and more references to these theories and have in turn helped refine and correct earlier models. The consistent improvement of the theories is in principle commendable but makes it more difficult for comparisons and evaluation. One such example is Mayer's (2005b) comment that the model of Schnotz and Bannert (2003) does not emphasize limited working memory. However, Schnotz's (2005) later model states: "Text and picture comprehension take place in cognitive architecture including a working memory of limited capacity" (p. 56). It needs to be said, however, that Mayer (2005b) also acknowledges that the two theories are compatible and similar. Furthermore, researchers agree that an all-encompassing theory is missing and that these theories still need a wider research foundation and future results to bolster the findings (Clark & Paivio, 1991; Schnotz, 2005).

A first difference between ITPC and CTML is their origins. Schnotz's theory stems from research done at the University of Koblenz-Lendau in Germany, whereas Mayer's research is from the University of California, Santa Barbara in the USA. I have found European articles (e.g., Molinari & Tapiero, 2007) that quote Schnotz and American literature preferring the theory by Mayer (e.g., Carney & Levin, 2002). This distinction should not be taken as the main difference since both authors seem to be in continual contact and both acknowledge large overlaps in their theories. The following will attempt to distinguish between the two. However, it is important to note that the differences are not meant to point at contradictions or prove the other theory wrong, but rather are attempts to explain a certain concept or process in more detail.

The strong point of the integrated theory by Schnotz is its ability to explain the differences between the sensory and cognitive modality and the different principles of representation. Another benefit is that assumptions of interference of mental model construction were correctly predicted with ITPC. Schnotz et al. (2002) hypothesized that adding irrelevant or task-inappropriate pictures can interfere with mental model construction from text. Results supported the hypothesis with college students showing interference of mental model construction with task-inappropriate illustrations. ITPC further distinguishes itself, but with the assumption that mental models are more easily generated by pictorial information (since it is in the same channel) than from textual information (Molinari & Tapiero, 2007). Brünken, Steinbacher, Schnotz, and Leutner (2001) give an example where Mayer's theory of two separate mental models might not be adequate. According to CTML, a text on an instruction to mentally rotate a geometric cube is being organized into a verbal model. However, a verbal model would not suffice to perform a mental rotation of a cube. ITPC on the other hand assumes that the verbal information is generated into a pictorial model, which lends itself much more to the task of the required operation.

CTML's strength lies in its focus on the importance of the limitation of working memory. Closely related to the concept of a limited capacity is the concept of cognitive loads, which is based on research by Sweller and Chandler (1994). The concept of cognitive load has proven to be an effective way of predicting and explaining several positive and detrimental effects of various stimuli. Furthermore, Mayer's theory is referenced in most recent research on the topic of multimedia learning and holds a wide acceptance by researchers.

In sum, both theories are closely linked and have their strengths in focusing on different elements of the processes involved in learning in a multimedia context. CTML is better at explaining settings that are beneficial or detrimental to learning with its focus on cognitive loads, whereas ITPC is more elaborate in explaining the positive or negative effects in constructing mental models and describes the coding from various modalities in more detail. Both authors agree that more research is needed to validate and unify the theories. Mayer (2005b) stresses the importance of further research in assessing and measuring cognitive loads and determining how learners build mental models. Mayer also stresses the importance of reconciliation between all theories mentioned above. Schnotz (2005) proposes research on the dual coding theory, more specifically the question of whether the verbal channel is an entity or comprises subchannels. Furthermore, research is needed to measure and test hypotheses concerning the construction of mental models. Further research efforts should also be made in the area of learner characteristics and learning strategies (also see learner characteristics below). Last but not least, in order to ensure a productive and useful theory of multimedia learning, testable predictions should be derived from the theories and tested in scientific experiments (Mayer, 2005b).

Nature of Materials

The previous section of theoretical foundations investigated 'how' questions (How does human cognition work? How do pictures facilitate learning?). In the following section the focus will turn to the questions of why, what, and when (Why do pictures help? When and what kind of pictures should be used?). The functions of text and illustrations will be discussed, as well as considerations are made on test characteristics and subject-specific material.

Functions of Illustrations

Several excellent reviews on text-picture effects on learning have been published over the last three decades (e.g., Carney & Levin, 2002; Levie & Lentz, 1982; Levin et al., 1987). There is consensus that in most of the reviewed literature there are significant positive effects of illustrations on learning. As was mentioned in the introduction, it soon became apparent that a more differentiated look at the question of whether illustrations facilitate learning was necessary. Hannus and Hyönä (1999) stated: "More recently, research has concentrated on disentangling the relevant conditions needed to obtain illustration benefits in learning and the underlying reasons for these beneficial effects" (p. 97). One obvious observation is that there are several kinds of illustrations. In multimedia research the classification by Levin (1981) is the most prevalent. The author proposes five functions of pictures.

1. *Decoration Function*: Illustrations that are not related to the text and serve only to make a text look more attractive (and do not support critical information) are decorational (see for example pictures and text).

2. *Representation Function*: Pictures that represent actors, objects, or important aspects of the text and 'tell' the same story as the text are representational in nature. Representational pictures are usually seen in narrative passages and are very prominent in text (e.g., when talking about a ship, illustration depicts a ship).

3. *Organization Function*: Illustrations and diagrams that show 'how to do it' or show several characters and objects and their relation are organizational (e.g., pictures showing how to do CPR or how to use a fire extinguisher).

4. *Interpretation Function*: Illustrations that help understand abstract or difficult passages are interpretational. These pictures are prevalent in science or social studies, explaining abstract concepts and making them more concrete for the reader (e.g., comparing the heart with a pump).

5. *Transformational Function*: Illustrations that help recode, relate, and retrieve information and serve as a mnemonic aid are transformational. These illustrations are very rare and mostly absent from textbooks.

This classification of illustrations has proven to be useful and has been cited by many studies in the field. The different types of illustrations also have different effects on learning. In their meta-analysis of 150 studies, Levin et al. (1987) found an average effect size for illustrations of .71. Decorational pictures showed no effect; representational, organizational, and interpretational pictures showed effect sizes ranging from .5 to .75, whereas transformational pictures showed an effect size of 1.33.

While this classification helps purposes of definition, it does not shed much light on why illustrations help with learning texts. Levin and Mayer (1993) proposed seven Cs or seven reasons why text comprehension is facilitated by adding pictures. Illustrations make information in text more

1. *Concentrated*: Important information is summarized and the essence of the text is brought to the fore.

2. *Compact/concise*: Converts hundreds of words into an efficient form.

3. *Concrete*: This reason corresponds with the representational function mentioned above. A pictorial representation can convey information in pictorial and verbal form which increases memorization (see dual coding theory above, or multimedia principle below).

4. *Coherent*: This reason corresponds with the organizational function. Coherence can be achieved by the inclusion of maps, graphs, flowcharts, and taxonomies (see Winn, 1987, for an extensive review and definitions of charts, graphs, and diagrams).

5. *Comprehensible*: This reason corresponds to the interpretational function. Illustrations help readers with low prior knowledge to understand the text (e.g., elements of a cell or process of cold fusion, etc.).

6. *Correspondent*: Illustrations can construct relationships between unfamiliar elements or concepts. Illustrations integrate information and pictorial analogies can help with comprehending obscure texts.

7. *Codable*: This reason corresponds with the transformational function. Difficult-to-remember information can be coded by several mnemonic strategies, of which transformational pictures are one example. These illustrations are expected to show the highest learning effect since text only versions make memorizing lists of plant names of unfamiliar Latin names extremely difficult without mnemonic tools.

This list of reasons is not empirically derived, and does not claim to be conclusive or correct. The authors point out the limitations of the list, but hope to give some background or foundation for future research. Several of the reasons can be bolstered by research findings (also see multimedia principles below), but further research needs to be done.

Five functions of illustrations and seven reasons for illustrations being facilitators for learning have been presented. This section ends with a reference to two articles, where recommendations for the use of illustrations are given. In 1987, Levin et al. formulated a list named Ten Commandments for Picture Facilitation. While that list was thought to be humorous, many of its components have proven to be meaningful. A decade later Carney and Levin (2002) reformulated and updated the list now named 10 Tenets for Teachers. The interested reader will find the tenets as a good summary of the above content with additional applications for practice.

Types of Texts

While much research has been done on classifying illustrations and researching which illustrations are most effective, research on characteristics of text is scarce. Issues arise on how to classify text and which type of text is most beneficially illustrated.

Distinguishing between expository and narrative texts is one way of classifying discourse. Expository text is non-fictional writing and is found in most textbooks and scholarly writings. Narrative text, on the other hand, is narrated and story like, which is prevalent in storybooks. This distinction of texts has proven to be useful. The literature reports differences in the processing and remembering of narrative and expository texts (e.g., Einstein, McDaniel, Bowers, & Stevens, 1984; Wolfe & Mienko, 2007).

In their review, Levie and Lentz (1982) listed the nature of text in the 55 articles they reviewed. Most of those articles were expository; however, no further analysis or distinction between different types of texts was made. Although some studies used narrative texts (e.g., Haring & Fry, 1979; Holmes, 1987) and reported positive effects of pictures, the first study to investigate the effect of type of text was Wadill, McDaniel, and Einstein (1988). The authors state that no study had previously been done that compared the effects of illustrations across types of texts. The results indicate that the effects of pictures are not the same across all texts. Even though pictures enhanced memory when tested with free recall, cued recall memory was increased only for expository texts. While this study shed some light on the effects of texts, several other variables were not considered in this research. Previous knowledge, for instance, has proven to be a decisive factor for the effect of pictures (see principles of multimedia below) but was not included in this study. Nevertheless the study by Wadill et al. (1988) was a first attempt to differentiate between types of texts. Unfortunately no further research has been done in this direction.

Levin and Mayer (1993) note that the issue of type of text has been mainly ignored in multimedia research. To my knowledge, no research has been done since the observation by Levin and Mayer and the study by Wadill et al. This lack of research is even more astounding, since research on expository and narrative texts and its relations to learning and memory are being continually studied by linguists and by studies on text processing.

The scarcity of research on this topic can be explained by the comparison of importance of narrative and expository texts in terms of learning environment. Textbooks are the most important media to convey knowledge in schools (Mayer & Gallini, 1990). Expository texts are thus a lot more prevalent in learning than are narrative texts. Most researchers thus choose expository texts for their experiments, and narrative texts have mostly been ignored. Nevertheless more research is needed to investigate the different effects of pictures on types of texts.

Test Characteristics

Another variable has not received much attention in the research on multimedia learning. The issue of how to test for memory, retention, or understanding of a processed test can be approached in different ways. Most studies use a cued recall test such as multiple-choice questions (e.g., Levie & Lentz, 1982). However, memory can also be tested in other ways such as free recall. There are several advantages and disadvantages in both ways of testing. While cued recall can be more reliable for scoring purposes, only insight into tested information is available. Free recall, on the other hand, can give insights into learning processes and a wider range of learned information. There are, however, issues of scoring and interrater reliability (Waddill et al., 1988). Furthermore, test questions can address cognitively different goals: remembering or understanding

(Mayer, 2005b). Retention tests ask for reproduction of a text such as in free recall questions or in recognition questions, such as true-false or multiple-choice questions. On the other hand, meaningful learning attempts to test the ability to understand. A well-understood topic can be transferred and applied to novel situations. In transfer tests, problems are formulated in a way that do not explicitly give the same information as the previously read text; that is, the individual has to apply his or her knowledge to the new problem or situation.

Mayer (2001) reviewed nine studies that he and his colleagues had done in the previous years and compared them according to which type of test was administered. In the six studies that tested for retention (typically with free recall) in a text-based context, students with illustrated text recalled more elements than a control group of text only. Effect sizes ranged from -.07 to 1.33 with a mean of .89. The same six studies also tested for transfer with questions on problem solving and generating creative solutions. Again the multimedia setting outperformed the text-only group. Effect sizes ranged from 1.0 to 1.71 with a mean of 1.36. It can be seen that illustrations showed higher effect for transfer test than for retention tests.

Both CTML and ITPC agree that illustrations enhance the construction of mental models. It is thus evident that testing for understanding and transfer requires correct mental model construction more so than when testing for retention. Nevertheless the distinction between remembering and understanding is not prevalent in studies of multimedia learning. The mentioned review by Mayer (2001) dealt only with physical systems such as brakes, generators, and pumps. Hence, research on more diverse content is needed and future research should clearly state whether knowledge or understanding is being tested. Mayer (1997) stresses the importance of the distinction of measuring retention or meaningful learning: "Had we focused solely on retention of the presented material, we may not have obtained a contiguity effect" (p. 18; see below for explanation of contiguity effect). Many research studies have shown positive effects of illustrations on learning. These positive effects can greatly be enhanced by testing for meaningful learning instead of testing for simple knowledge.

Another issue pertains to the timing of testing. Criticism has been voiced that most research tests only for immediate recall and little is known of learning effects over long periods of time (Atkinson, 2005). To the best of my knowledge the study by Segers, Verhoeven, and Hulstijn-Hendrikse (2008) is the only one that tested for short- and long-term recall. The authors mention evidence of a reversed modality effect in studies that tested for long-term recall. In Seger et al.'s (2008) study 113 ten-year-old school children were randomly assigned to four groups. The subjects were presented with either an oral or a written format and were furthermore distinguished if illustrations were present or not. Both retention and transfer were tested immediately after testing and 1 week later. Measures of short-term learning revealed an expected positive modality effect of oral presentation (with picture) when compared to written presentation (with picture). However, the measures from long-term learning failed to support that evidence. No difference was found 1 week later. Similarly the multimedia effect was found only for the oral condition. While this study is a much needed addition to the research, there are several limitations that need to be considered. Only representational pictures (and maybe even just decorative) were used, which have been shown to obtain only small effect sizes (Levin et al., 1987) and the authors also mention only moderate relevance for the pictures. The most significant limitation however is the failure to account for prior knowledge. Several children seem to have already been exposed to the material. Nevertheless the study addressed a much neglected area of multimedia research and more efforts should be made to compare short-term and long-term effects of illustrations.

Comparisons of Media

Several research studies have tried to compare effectiveness of different types of media. Fletcher and Tobias (2005) note however that "media comparisons have been the subject of considerable and often inconclusive research" (p. 118). Mayer (1997) goes as far as calling the question unproductive. The following is only a very brief overview of results concerning questions of type of media (e.g., Are computers more effective than textbooks?). Tobias (1982) argues that the choice of medium has little effect on the outcome; however, comparisons are often made very difficult since different media often incorporate different methodologies of teaching and learning. Mayer (1997) analyzed nine studies that compared computer-based with text-based learning. The results showed a minor positive but inconsequential effect for computer-based learning. Again instructional methods were not comparable (text-based material contained more words than computer-based version, where only main points were summarized). These findings suggest that it is not the medium that has an effect on learning but the way the medium is used and which cognitive processes are required by the task (Fletcher & Tobias, 2005). It is the consensus of many researchers (Mayer, 1997; Tobias, 1982, Fletcher & Tobias, 2005) that the question of the effectiveness of different mediums is no longer relevant. This opinion is expressed quite forcefully in the title of an article by Clark (1994):

"Media will never influence learning" (p. 32). The author calls for research on instructional methods and their cognitive consequences rather than investigations on the media per se.

Settings

Considerations on the setting of material are also of interest. Most research on the topic of multimedia learning is basic research, and not many studies are reported that use more authentic settings. Hannus and Hyönä (1999) argue, in one of the few studies with authentic materials, that one difference to basic research can be found in the amount of illustrations shown. Many research studies report layouts of one text accompanied by one illustration, while authentic textbooks typically show several illustrations on a page. Segers et al. (2008) agree that studies in authentic school settings are quite scarce. The authors mention several reasons why Mayer's CTML cannot be directly applied to school settings. First, most results have been obtained with college students, second most research is done with material of higher complexity, and third there is evidence that modality effects can be reversed when long-term recall was involved. More research is needed in order to establish principles and guidelines that are not only based on basic research but have been proven to be applicable in authentic learning situations.

Considerations on Content Areas

Research on multimedia learning has attracted attention from various disciplines. The following is a brief overview of subject areas that have received extensive interest from researchers. This section often exceeds the delimitations set at the beginning of the review. Most research interested in a certain subject and thus interested in application and practice often incorporates animated illustrations, videos, and other non-static pictures and text. Since this literature review is delimited to static pictures and text, differences will not be discussed or explained further. Three content areas will be discussed and references are made to more detailed articles on the topic for the interested reader. The first two areas (mathematics and physics) have been chosen since they are incorporated in the research design by the most prominent authors in the field. The third area (reading) was chosen since there is much controversy in the literature and contradictions were found in research on that content area.

Mathematics and geometry are prime example of areas where pictures or diagrams can be used to facilitate learning. Many textbooks encourage solution processes that require the student to draw diagrams. Moreover many geometry problems would be extremely difficult if not impossible to understand in the absence of illustrations (Sweller, 2005b). Research on geometry is thus an ideal topic for research on cognitive processes. The theory of cognitive load (Sweller et al., 1998) has mostly been used with the topic of geometry. Several principles of multimedia learning (see below) have also come from research on mathematical problems (e.g., split attention principle). Not only static diagrams and text have been proven to facilitate learning, but also animated diagrams or processes have been implemented in practice with great success. For instance the computer program ANIMATE (Nathan, Kintsch, & Young, 1992) helps students solve algebra word problems by using animations which are generated by user interaction. The study by Nathan et al. showed larger pre- to post-test gains than control groups that did not use the computer program. Similarly, Moreno and Mayer (1999) report that animation in learning how to add and subtract can help students solve more difficult questions.

Even though there are several researchers who have used mathematics in multimedia research, the literature is rather small (Atkinson, 2005). In a review by Moreno and Mayer (2002) of 31 recent studies on multimedia learning, only 1 was on the topic of mathematics. Furthermore, most research has dealt with geometry (research by Sweller), a sub-domain of mathematics which naturally lends itself to test assumptions. Research needs to incorporate other non-geometrical areas of mathematics as well. Another limitation of the literature of multimedia learning in mathematics is the participants. Many studies use college-age students and some have used elementary students, but a theoretical foundation that incorporates developmental factors is missing. More research needs to address how age and prior knowledge affect learning. Another criticism has been voiced that most research tests only for immediate recall and little is known of learning effects over long periods of time (Atkinson, 2005).

Many research studies and a wide variety of articles from the most distinguished authors in the field of multimedia learning have been done on the topic of physical systems. Most common topics involve, for instance, car brakes, lightning, and tire pumps (research by Mayer and colleagues, e.g., Mayer & Moreno, 2002) and on pulley systems (research by Hegarty and colleagues, e.g., Hegarty & Just, 1993). In mechanics, motion is often an integral part and can be visualized in several ways. Static and animated diagrams can help generate a mental model of motion. Developing a mental model from a static diagram involves some type of inference or interpretation since motion can be represented only by arrows or by a sequence of illustrations. Animated diagrams on the other hand are more realistic and have the benefit over reality that they can focus on essential parts of a process and can speed up or slow down motion (Hegarty, 2004). The two qualitatively different aspects of static and animated diagrams justify the question of which is more effective. However, when comparing the effectiveness of static versus animated diagrams in learning, Hegarty (2004) found no difference in outcomes between the two. Nevertheless, diagrams are an effective teaching method. Illustrations not accompanied by text can be enough to learn about physical systems. Hegarty and Just (1993) showed static pictures of pulley systems to participants who were later able to explain how the systems worked. However, the combination of text and static picture in a second experiment was found to significantly increase learning. Although the multimedia principle (see below) has been shown to also apply to the learning of physics, several questions still need to be addressed by further research. Personal characteristics such as prior knowledge and spatial ability have proven to affect learning outcomes (Hegarty, 2004). More research is needed in order to establish when dynamic or static images should be chosen as well as determine how abilities, skills, and knowledge of the student influence outcome.

Research on multimedia learning in the content area of reading has caused much controversy. As was previously mentioned, research on multimedia learning was very slow to develop. Several of the first articles published on this topic were done with children and tested for effects of illustrations on reading. In a review by Samuels (1970) the effects of illustrations were thought to be nonexistent or detrimental to learning. In the meantime, research has proven that illustrations are very effective and facilitate learning, and the initial negative effects have been explained by methodological issues and also by the choice of content area, that is, learning to read (Lemonnier-Schallert, 1980). Furthermore, until today the right method of teaching children how to read is still a great debate which is often called the 'reading wars' (Reinking, 2005). Literature on reading in terms of multimedia learning is extensive but shallow, with many disciplines showing interest such as pedagogy, psychology, philosophy, linguistics, media, and journalism (Reinking, 2005). However, the multitude of disciplines interested in reading and the research articles published have failed to specifically address reading in terms of multimedia learning. A review of computer-assisted instruction in reading reports an effect size of .2 for the inclusion of illustrations (Blok, Oostdam, Otter, & Overmaat, 2002). However, the authors cautioned against a too optimistic use of computer instruction since many of the reviewed articles were of poor quality. In a review of the research on multimedia in learning to read, Reinking (2005) mentions two principles that have the most empirical basis. The first is that synthesized or recorded speech is very beneficial in helping students decode letters. Computer programs that make use of recorded speech and provide individual assistance show benefits for beginning readers. Second, there is evidence that immediate access to meaning of unfamiliar words enhances vocabulary. There is much room for further research in the area of multimedia learning. Future research could investigate how to influence motivation, where and when technology should be used, as well as to generate a theoretical basis that could explain how technology could effectively be used in practice.

Only three content areas and their relations to multimedia learning have briefly been mentioned. For a more extensive review on these areas as well as on others such as history, chemistry, meteorology, second language acquisition, and cognitive skills see Mayer (2005a).

Learner Characterstics

Winn (1987) mentioned that the effectiveness of illustrations cannot be explained only by the presence of the medium. Many studies have found the effects to be dependent on students' abilities. The following will discuss several learner characteristics that have been reported in the literature. Hence this section is concerned with the question of For whom are illustrations beneficial?

Age

There seem to be fundamental differences in how adults and children study and interpret pictures (Peeck, 1987). In Peeck's review on how illustrations facilitate the processing and remembering of text, several pages were dedicated to learner characteristics. A number of variables were found to differ according to age. Preference, approach, interpretation, and use of illustration are different depending on the reader's age. For instance, while an active processing approach to studying illustrations is assumed to be fundamental, younger children only gradually learn how to approach and interpret illustrations. Only with practice and guidance by teachers can children learn how to use diagrams, charts, and other illustrations (Peeck, 1987). Adults have learned to look at pictures in a more systematic and active way and are thus able to use illustrations more beneficially. Several researchers have called for more research in order to be able to generalize research findings across grade levels (Atkinson, 2005). However most research studies are done on either college students or elementary children (Hannus & Hyönä, 1999) and little is still known how the two differ in terms of multimedia learning. One reason why age has widely been neglected is that it is often correlated with other variables such as abilities, skills, and knowledge. It is assumed that with age all these variables increase as well, making it thus difficult to distinguish among these highly correlated variables. Abilities and knowledge are two variables that have been researched more thoroughly and will be discussed below. Nevertheless, future research needs to find explanations for developmental influences and determine which multimedia settings are best used at which age and grade level.

Ability

Hegarty and Just (1993) used eye-tracking in order to determine how text-picture combinations facilitate learning. Additionally the authors grouped the subjects by their mechanical ability (as measured by a mental rotations test and a mechanical comprehension test) into low and high. Results from experiment 1 suggest that subjects who study text and picture together did better on a retention test than if they studied either medium alone. In experiment 2, the authors found significant differences between high- and low-mechanical-ability students. It seems that low-mechanical subjects have more difficulty in generating a mental model from text and picture and thus show different strategies when reading the diagrams. Low-mechanical-ability students reread passages in a text more often and switched between text and diagrams more often. While this study is an example of a growing body of research on how different abilities affect learning in a multimedia context, there are several limitations to the study. First, the second experiment consisted only of 9 subjects and several differences (e.g., inspection time, etc.) did not reach significance. Furthermore, in this case mechanical ability is correlated with prior knowledge, since the mechanical comprehension test measured knowledge about mechanical operations. Prior knowledge is known to affect learning in a multimedia context (see below). It is thus not clear if the general ability in a subject or specific knowledge on the topic is the reason for the observed differences.

The ability that has received most interest by researchers is reading ability. Already Levie and Lentz (1982) in their much cited review on the effects of illustrations concluded that pictures might somewhat benefit poor readers better than good readers. Several theories predict a positive effect of illustrations for poor readers. Even though the dual coding theory (Paivio, 1986) does not make any specific references to reading ability, Winn (1987) believes that the theory explains why the combination of illustrations and text is more beneficial for low-ability readers than for high-ability readers, since illustrated text uses both the verbal and the visual channel. ITPC theory, however, makes clear predictions concerning reading ability. Schnotz (2005) argues that prior knowledge, the visual channel, and the verbal channel all contribute to generating a mental model. If prior knowledge is high, the medium (text, picture, or both) is not of great importance. Similarly because poor readers have a deficit in conveying information through the verbal channel, the pictorial channel increases in importance and thus the presence of illustrations should provide higher benefits for poor readers than for good readers.

In reviews on research with low- and high-ability readers, these positive effects of illustrations for poor readers have indeed been found (Peeck, 1987, 1993; Winn, 1987).

However, there are also reports of opposite effects. Reid and Beveridge (1986) reported that higher ability students benefited more from the presence of illustrations. It needs to be noted, however, that reviews on abilities (e.g., Peeck, 1993) not always clearly make a distinction between abilities (e.g., reading ability, general ability, prior knowledge). For instance Reid and Beveridge (1986) do not measure ability directly but use 'common within school measures' to distinguish between subjects. Nevertheless, Peeck (1993) believes that there is no contradiction in these findings. It seems that in general, poor readers benefit more from illustrations than good readers. However, this effect is only observable if the presented material is on a level that makes extraction of information possible. If poor readers are not able to extract information from either text or from the illustrations because of limited ability or high complexity of the material, positive learning effects should not be expected. Winn (1987) comes to similar conclusions and suggests that authors need to limit the amount of detail and information that is included. There is no knowledge, however, what these limits might be and at which point the level of complexity or the addition of details might interfere with learning.

In sum, student abilities have an effect on outcome variables in multimedia contexts. Reading ability has been the most researched and theories predict higher benefits for poor readers than for good readers when illustrations are present. These predictions have been validated by a variety of research findings; however, opposite effects have also been reported. More research is needed to establish when complexity level or the presented material could interfere with learning.

Prior Knowledge

In their research with effective learning environments, Kalyuga, Chandler, and Sweller (2001) reported that well-detailed instruction showed positive learning effects. However, they found an interesting trend that the same layout showed decreased efficiency with non-novice participants. Testing more knowledgeable subjects revealed that a diagram-only format was more effective than fully explained examples. This effect has already been observed in the review by Levie and Lentz (1982) where low prior-knowledge students seemed to benefit most by texts that were illustrated.

The influence of prior knowledge is also predicted by the integrated theory of text and picture (ITPC, see above). According to ITPC, low prior-knowledge students have little source of information to generate mental models from LTM and the presence of illustrations thus enhances learning. High prior-knowledge learners do not need to rely on illustrations since they are able to activate existing models from LTM. Consequently, low prior-knowledge learners benefit more from illustrations than high prior-knowledge learners (Schnotz, 2005).

Even though this effect was replicated in several studies, Kalyuga (2005) cautioned against a careless application. Several limitations need to be considered. First, measuring the level of prior knowledge is mostly collected by a questionnaire which often lacks sufficient depth and diagnostic potential. Furthermore, this effect has most strikingly been reported only in longitudinal studies, where the same subjects had to repeat similar assignments. Future research needs to address these issues and further efforts need to be made in order to develop appropriate instructional designs for different expertise levels. Nevertheless, these findings have been persistent across many areas, and research on multimedia learning needs to take this principle into consideration and efforts need to be made in order to control for knowledge level. For a more detailed review on prior knowledge and its relation to learning, see Kalyuga (2005).

Intelligence and Memory

Memory is considered to play a vital part in text processing (Just & Carpenter, 1992). In 2003, Kaakinen et al. examined how prior knowledge and working memory span affected recall of expository text. Results suggest that high working memory readers can allocate attentional resources more appropriately than low working memory readers. High WM readers spent more time on relevant information during processing, while low WM readers invested extra time after initial reading. While this research is indicative of the role WM plays in text comprehension, this specific article dealt only with text and not with illustrated text. To my knowledge there are few studies that distinguish subjects according to working memory and none have used it in a multimedia context. Intelligence and general ability have found more interest in research and the following will discuss how these abilities affect processes of text-picture comprehension.

Several studies looked at the effects of pictures on high- and low-achieving students. The results have proven to be contradictory. Hannus and Hyönä (1999) worked with 10-year-old fourth-grade students and report a significant benefit for both low- and high-achieving students if pictorial stimuli were present. However, there were differences between the two groups. Low-achieving students benefited from pictures in learning details, but pictures did not facilitate procedure or principle learning. High-achieving students benefited from illustrations regarding the learning of details, but were also able to understand principles and procedures. Reid and Beveridge (1986, 1990) reported different findings on the benefits of illustrations on low-achieving 14-year-old students. The authors report a positive effect on learning for high-achieving students. Pictures enhanced learning for up to 18% when a picture was present in comparison with text-only participants (Reid & Beveridge, 1986). Low-achieving students performed considerably less positive. The presence of a pictorial stimulus proved to be distracting. Low-achieving students looked at pictures on average twice as long as their higher performing peers (Reid & Beveridge, 1990) and the low-achieving group performed up to 19% less than the text-only group (Reid & Beveridge, 1986). Koran and Koran (1980) come to opposite conclusions. In their study with seventh- and eighth-graders, low-ability students performed significantly better when pictures were present if compared to a text-only group. High-ability students did not show any difference in performance with illustrated text. It is not immediately apparent why these differences occurred. There are suggestions that there is a developmental component that could account for some changes (Hannus & Hyönä, 1999).

These studies, however, have all focused on early to middle adolescence ranging from 10 to 16 years, thus limiting the explanation of a developmental factor. Another reason could be found in the difference between the clinical settings and the authentic school settings. Hence, studies that have used a more authentic approach could obtain different results. Another explanation can be that the lack of a coherent theory in the past decades accounts for the inconsistent and inconclusive research (especially for early studies). Studies have used different methods and have not consistently tried to find a theoretical basis for their findings (Mayer, 1989). The principles of multimedia learning outlined below have been established only in the last years, and many studies have not taken them into consideration in their research setup or in their conclusions. It is evident that the studies on multimedia learning are focusing on basic research questions and the applicability of these findings have not yet been tested on authentic textbook material. Most research designs use one or two illustrations in a text layout. Textbooks, however, generally used in classrooms differ from the typical research setting, in the sense that textbooks usually have several pictures and are seen at the same time (Hannus & Hyönä, 1999). Furthermore, as was mentioned previously, the complexity level of the presented material could be an explanation for the differences. Winn (1987) states that realistic pictures entail more information which makes it difficult for low-ability students to distinguish between important and redundant information. It is thus expected that low-ability students would benefit less than their more able counterparts. Peeck (1993) believes "a necessary condition for such a beneficial effect is an adequate level of picture-reading skill and prior knowledge in order to extract, understand and integrate the relevant information from the presented illustrations" (p. 232).

In sum, several reported results as well as predictions from theories indicate that, in general, low-achieving students benefit more from illustrated text than their more able peers. However, there is also evidence to the contrary. In complex situations with difficult illustrations and intricate explanations, higher-ability students could be the only group benefiting from illustrated text.

Visual Attention

Visual attention has been measured and researched in psychology for many years (Jacob & Karn, 2003). While processes and strategies involved in reading texts have been studied in many research projects, research on the combination of text and pictures is rather scarce (Hegarty & Just, 1993; Underwood, Jebbett, & Roberts, 2004). Research interested in the processes of learning in a multimedia context has to find ways to assess how text and pictures are used and read. Even though it would seem obvious to record where the eye is looking, many research studies have used other methods. In order to distinguish the time spent on text or illustration, researchers have used computers that show either the illustration or the text but never both at the same time. Subjects were able to push a button in order to switch between text and pictures (e.g., Reid & Beveridge, 1990). The method of a picture-text split was used in order to measure time spent on text respectively on the illustration and to count the number of transitions between text and illustration. While this method can generate very precise data and can be used for basic research, it falls short for implications into practice. Textbooks show multiple pictures and text simultaneously and the subject is not limited to studying only one without seeing the other. Reading text is not a straightforward process but both illustrations and text are integrated and it is suggested that eye-tracking can give valuable insight in order to understand the processes involved (Stolk, Boon, & Smulders, 1993). The following outlines results from eye-tracking studies that investigated text-picture combinations.

Are there individual differences in subjects when reading illustrated texts? Again, research on reading strategies for expository text is more abundant and several results have shown interesting results. In a study with college students, Hyönä, Lorch, and

Kaakinen (2002) investigated global processing strategies involved in reading expository text. Four different strategies were found and put into categories according to scores on reading speed, rereading parts of the text, and sequence of reading. About half of the sample of 48 students was termed fast linear readers. This group seemed to be effective and efficient readers who showed high reading speeds and read the text from start to finish with little rereading. Another group (28%), termed slow linear readers, showed similar characteristics like the previous group except for their slow reading speeds. Furthermore this group showed the lowest reading span and had the smallest scores on retention tests. The last group (15%) was topic structure learners. These readers showed a different strategy than all other groups. The subjects read the text not in a linear way but consistently reread passages, spent more time on captions and titles, and directed visual attention to pertinent sections. Topic structure readers showed the highest retention scores and highest reading spans. Another tentative group was named nonselective reviewers but only 2 subjects were in that group, which made comparisons difficult. Furthermore a follow-up study (Hyönä & Nurminen, 2006) failed to reproduce this group. However, Hyönä and Nurminen found support for the other three strategies. It seems that fast and slow linear learners as well as topic-structure readers can easily be distinguished by eye-tracking variables. Further research is needed in order to establish these findings. Several limitations need to be considered. First, these strategies have only been established with university student samples, which can be assumed to have high abilities in reading and language. Future research should incorporate a more diverse sample among adults. Additionally, it needs to be established if there are really three groups or only two. Hyönä and Nurminen (2006) already mentioned that their results might suggest that there are only two groups (linear readers and topic structure readers) since the first study found fast-linear and slow-linear readers comprising 48% and 28% of the sample while the follow-up study found percentages of 16% and 66% for the respective groups. Nevertheless, there is strong evidence that at least two different strategies can be distinguished when reading texts.

Similarly, Hegarty and Just (1993) found two different strategies among college students when inspecting illustrations. One group (high-ability students) analyzed illustrations of pulley systems in a short amount of time and fixated only a small number of components. The second group (low-ability) spent longer times on the diagram and had longer and more fixations. The findings, however, are limited in several ways. The small sample size of 9 subjects does not hold much significance in inferring results onto a larger population. Second, the results might be limited to physical systems such as pulley systems. More importantly the study did not distinguish between high prior-knowledge and low prior-knowledge students, which can be one explanation why the results differ from the ones from Hannus and Hyönä (1999). In their second experiment, the authors found that higher ability students retained information better from illustrated text and showed different strategies when reading. Higher ability students spent more time rereading, spent more time on relevant sections, and made more saccades between text and picture.

Even though there is contradicting research, there is evidence that there are strategies of reading and studying illustrated texts that differentiate between good and weak learners. More research is still needed on how to quantify strategies and according to which variables. Research studies that have studied strategies are limited in several ways. The most conclusive evidence on learning strategies concerns only learners of text (Hyönä & Nurminen, 2006). Other research is limited in sample size and has methodological issues (Hegarty & Just, 1993). Also some research was done with elementary children and beginning learners (Hannus & Hyönä, 1999) and not much is known about other populations. Since research with eye-tracking is very limited, more studies are needed in order to confirm these findings.

In sum, research investigating strategies involved in multimedia learning is very limited. There is some indication that different strategies differentiate between learners and outcome variables. However, it is not clear how to measure or quantify these strategies and this research area shows great promise for future research endeavors.

Principles of Multimedia Learning

The previous sections were concerned with the theories on multimedia learning, with the nature of the materials as well as with learner characteristics. The following is a presentation of principles that have emerged from an abundance of research. While the most ideal characteristics of text and illustrations have been mentioned, and evidence was given of who might benefit best of certain contexts, the focus will turn now to the interaction of these variables and will summarize already mentioned results in a concise format. Research has shown that illustrations need to be related to the text and be of good quality, and furthermore the text needs to be related to the illustration (Levin & Mayer, 1993). However, research has gone much more in depth in order to analyze the relationship between pictorial stimuli and texts. The abundance of research on these topics has made it possible to formulate principles of multimedia learning that have been supported by various research findings. The principles were chosen in regard to this study (static, non-verbal text and illustrations). Principles referring to solely audio, animation, video, etc., are not listed (although several principles mentioned could be transferred to those areas as well). The following structure and naming of the principles are based mainly on Mayer (2005a); however, other primary research articles are mentioned that support the principle. For a more extensive presentation of principles see Mayer (2002, 2005a) or Fleming and Levie (1978, 1993). (The interested reader on principles that are commonly mentioned and applied but are questionable and show little if no foundation in research is referred to Clark and Feldon [2005]. The authors present a review on five of such common but questionable principles.)

Five principles including principles on multimedia, split-attention, modality, prior knowledge, and contiguity principles are discussed in detail. Several additional principles are described briefly and references are made to more detailed reviews.

Multimedia Principle

Why not use text or pictures alone? Hundreds of studies and several reviews on studies looking at the effects of pictures and text show that the combination of both enhances learning (e.g., Carney & Levin, 2002; Levie & Lentz, 1982). Medium effect sizes are reported to range from .55 to .71 (Levie & Lentz, 1982; Levin et al., 1987), to more recent findings showing effect sizes of 1.37 (Mayer, 2002). The multimedia principle is probably the most extensively researched principle and is widely accepted. Thus, the multimedia principle states that learning is enhanced if there are multiple opportunities to gather information (i.e., text and picture). While this principle has been found to be stable across many settings, the questions of why and how still cannot be fully explained. Dual Coding theory (see above) is a widely accepted method to explain the multimedia affect, but questions still remain on why pictures are detrimental under certain conditions or to whom it is most beneficial (i.e., low- or high-ability students). Further research also needs to be done in assessing and measuring cognitive loads, and a better understanding is needed of the multimedia effect in terms of short-term and long-term benefits. For an extensive review on this effect, see Fletcher and Tobias (2005).

Split-Attention Principle

The split-attention principle is based on the theory of cognitive load (see above). Initial research with students who solved mathematical or geometrical problems found that if attention has to be split between different modes of presentation (i.e., diagram and text) extraneous cognitive load is generated and thus learning is limited (Tarmizi & Sweller, 1988). When the diagram and the corresponding text are not integrated and neither one is not enough to understand the problem, cognitive resources are needed to integrate two sources that are split. Physically integrating diagrams and text has proven to reduce extraneous loads and increases learning with quicker response times and fewer errors (Ward & Sweller, 1990). The split-attention effect has since been found to be of use in explaining several findings across disciplines such as mathematics, geometry, physics, and biology (Ayres & Sweller, 2005). The split-attention principle thus states that information that needs to be mentally integrated should be presented in an integrated form, both physically and temporally, in order to reduce cognitive load and free capacity for learning.

Several issues remain that need to be further investigated. It is not clear how the physical and temporal integration can be achieved in various areas. In addition, measuring whether information is unintelligible in isolation could be correlated with prior knowledge and thus more research is needed to see how prior knowledge is affecting the split-attention principle. It was also already mentioned that cognitive loads are often assumed but not directly measured. In order to bolster the findings of this principle, future research should be targeting these issues. For an extensive review and presentation of the split-attention effect, refer to Ayers and Sweller (2005).

Modality Principle

The modality principle is a based on the dual coding theory and the cognitive load theory (see above). Subjects learn better if multiple modes are present (i.e., narration and graphics instead of reading and graphics). Working memory is limited and consists of a visual and an audio channel (Baddeley, 1992; Paivio, 1986). Research that involves shadowing (repeating auditory prose passage) has shown interesting results when subjects are asked to remember words presented in different formats (i.e., visual or auditory). Several research studies show that the mode of presentation of words to be remembered does not affect retention with absence of shadowing; however, shadowing reduces retention for auditory words but not for visual words (e.g., Rollins & Thibadeau, 1973). It appears that cognitive load is increased of whether information is presented through only one channel. Further research investigated the assumption of whether the use of both channels would increase retention. Tests on digit memory span have supported this assumption. When presenting participants with digits in an auditory, visual, or combined method significantly more numbers are remembered in the combined format than with either of the single presentations (Frick, 1984). It needs to be mentioned, however, that information presented through two channels is not the sum of the individual channels; nevertheless, there is a significant increase in learning when using dual-mode strategies. In a more recent article, Brünken et al. (2002) used a dual-task methodology where the second task is a direct measure of cognitive load. Their results show a decreased performance of a visual secondary task when using visual first tasks, indicating an overload of the visual channel. Similarly Brünken, Plass, and Leutner (2004) replicated the dual-task methodology with auditory information. Again the secondary auditory task decreased with an auditory primary task showing increased cognitive load when the same mode of presentation is used.

The presented articles are only a few examples of a positive effect of combining visual and auditory information and also demonstrate the detrimental effects of not doing so. In a current review of the modality effect, Low and Sweller (2005) come to the conclusion that research "unambiguously established that performance could be enhanced by using dual-mode presentation techniques" (p. 152). In a review of several studies applying the modality effect, Mayer (2005c) found a positive effect on 21 of 21 studies with a median effect size of .97. It is thus evident that in a wide variety of situations, learners continually learn better with graphics and narration than with graphics and printed text.

The modality effect holds many practicable implications for instruction. Spoken text should not be presented with written text, but learning can be enhanced when spoken words are combined with illustrations or nonverbal animations. This principle can easily be applied in instruction (e.g., PowerPoint presentations) and e-learning environments.

Additional Principles

The following briefly lists several additional principles of multimedia learning. For more detailed information refer to the mentioned references.

1. *Spatial and Temporal Contiguity Principle.* Text and picture should be presented in close proximity rather than far apart and should be present at the same time. This principle is similar to the split-attention principle mentioned above, with the difference that text and picture in the contiguity principle are not both essential for learning as in the split-attention principle. But for the positive effects of illustrations on retention of text to be effective, both should be shown at the same time and in close proximity (Mayer & Anderson, 1992; Mayer, 2002). Research on this principle showed median effect sizes of 1.11 for the contiguity principle and 1.31 for the temporal contiguity principle (Mayer, 2005d).

2. *Picture-Text Sequencing Principle.* If text and picture cannot be presented simultaneously, present the picture before the text and not vice versa. When reading a text, several possibilities of building a mental model exist. If an illustration is shown after the text, the illustration might interfere with the already built mental model (i.e., imagining story settings from reading a book is most likely not the same as settings in a motion picture on the same book). Illustrations shown before the text, however, can facilitate building mental models and thus learning (Schnotz, 2005).

3. *Redundancy Principle.* Redundant material should not be added. Redundancy occurs when information is unnecessarily repeated. Cognitive load increases in order to distinguish between relevant and redundant information and should thus not be included (Mayer, 2005d; Sweller, 2005b).

4. *Coherence Principle.* Similar to the redundancy principle, extraneous material such as sound, music, or complicated graphics should not be added (Mayer, 2005d). Furthermore, a concise and coherent text with fewer words showed effect sizes of 1.66 over a text with more words and interesting details (Mayer, 2002).

5. *Signaling Principle.* Cues and highlighting of important sections as well as signaling organization by adding for instance "(1)", "(2)", etc., can facilitate learning and showed effect sizes ranging from .34 to .70 (Mayer, 2005d).

6. *Structure Mapping Principle.* If there are multiple visualizations for a passage, a picture that is appropriate and pertains to future solving tasks should be chosen. Material should be potentially meaningful (Levie & Lentz, 1982; Mayer & Gallini, 1990; Mayer, 1989; Schnotz, 2005).

7. *Prior-Knowledge Principle.* Low prior-knowledge learners benefit more from a multimedia context than high prior-knowledge learners. The ability to construct mental models is easier for high prior knowledge and thus the presence of illustrations can help low prior-knowledge students reduce cognitive load when constructing mental models (Schnotz, 2005). There is evidence that the same setup that facilitates learning for novices can even be detrimental for more experienced learners (Kalyuga, 2005). (Also see prior-knowledge above.)

Summary

Even though the use of illustrations in text and their role in learning has been known for centuries, research was slow to be interested in studying the effects of illustrations on learning, and it was not until the 1970s that articles were published on that topic (Houghton & Willows, 1987). In the last years, however, research has seen a veritable explosion of articles on that topic and multimedia learning has emerged as a discipline (Mayer, 2005a). Many questions were answered and many more have evolved. In several reviews over the last decades it has become evident that illustrations facilitate learning (e.g., Carney & Levin, 2002; Levie & Lentz, 1982; Levin et al., 1987). It is less clear however what the reasons for the observed benefits are. Several theories of multimedia learning have been proposed in the last two decades that explain the cognitive processes involved. More recently, questions have arisen of which variables play a role in defining effective multimedia contexts. This research review looked at several important variables: variables concerning the material (illustrations, text, settings, and tests) and variables of learners (age, intelligence and memory, prior knowledge, and visual attention). While there is impressive growth in research in finding relevant variables and explaining their interaction with others, a meta-analytic conceptualization is missing. In order to summarize and visualize all the information above I will present a diagram from Salomon (1989). Salomon's meta-analytic reflections on learning from texts and pictures have widely been ignored and I have found little evidence of references to his article. However, I believe that his 'map of the territory' is a valuable addition and summarizes the presented material well. Figure 3 consists of five clusters which represent variables that are involved in learning in a multimedia context: (a) Stimulus: the nature of illustrations and text and their interrelations; (b) personal variables: prior knowledge, abilities, motivations, age, etc.; (c) cognitions: inherent cognitive structures and processes; (d) nature of the task: memorizing, understanding, applying, summarizing, etc.; and (e) cognitive-psychological functions: the accomplished or realized functions. Stimuli and task have a variety of functions. While these qualities are already inherent in the material or the task, in this case it is the realization of these functions in contrast to their potential.

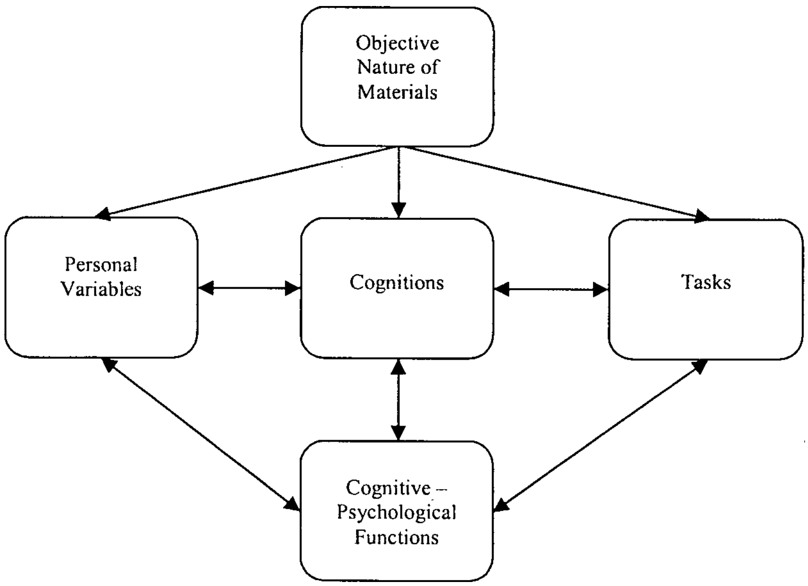


Figure 3. Variables involved in learning from text and picture. From "Learning from Texts and Pictures: Reflections on a Meta-Level" (p. 75), by G. Salomon, in H. Mandl and J. R. Levin (Eds.), *Knowledge Acquisition From Text and Pictures,* 1989, North-Holland: Elsevier Science Publishers B.V.

Learning in a multimedia context is complex. Many variables play a role and it is difficult to take into consideration all at the same time. However, Salomon (1989) believes that the model could help to explain research findings and specifically contradictory reports. For instance, in his article, two studies are presented that have very similar methodologies and research designs. Outcomes on passive or interactive video display in one study show no learning effect, while the other study found favorable outcomes for interactive video. With the help of Figure 3, however, these contradictory findings could be explained. While the nature of the material and the task were the same, personal variables were not accounted for and it can be assumed that the cognitive-psychological functions were not the same as well. While the setup of Figure 3 can easily be agreed upon, it would be extremely difficult to test the whole theory. It should thus be mentioned that the figure is presented here only as a summary and a visual help to understand the processes involved in multimedia learning that have previously been discussed in more detail.

In sum, illustrations, texts, and their combination have an effect on learning through their inherent properties as well as their generated cognitive processes. Furthermore, personal-, situational-, and task-properties serve as mediators or moderators of the processes involved in multimedia learning (Salomon, 1989). Multimedia learning is an exciting and growing research field with many implications for practice. The present study is contributing to the already existing literature in a unique and novel way and I hope will prove to be beneficial to theory as well as to practice.

CHAPTER 3

METHODOLOGY

This chapter outlines the methodology, research design, and purpose of the study. This research in educational psychology was interested in the field of multimedia learning. More specifically, the research questions refer to predictability of cognitive ability and working memory on visual attention and success in processing illustrated texts.

This research is based on established principles of multimedia (outlined in chapter 2). In accordance with the general redundancy principle (text and picture should not be combined for high prior-knowledge learners), only subjects with low prior knowledge were chosen. Furthermore, the selection of the textbook passages was based on the following principles: modality principle (spoken and written text should not be combined), coherence (no unnecessary sound or music will be used), spatial and temporal contiguity (text and picture are presented in close proximity), and the structure mapping principle (only illustrations that are appropriate and potentially meaningful were chosen). This research is of value, as the theoretical background has been established only in recent years, and to my knowledge there are no studies that tried to apply the findings in the field of cognitive psychology to an authentic context with adult subjects.

Type of Research

The design of the study is quantitative. The impossibility of manipulating the naturally occurring conditions (i.e., working memory, cognitive ability, etc.) requires a non-experimental design. The correlational approach to this exploratory research enabled the assessment of multiple variables and the relationship between the phenomena.

Population and Sample

The population is adults in the United States with a degree in higher education. The sample consisted of 62 college students (26 males, 36 females) from Andrews University with an average age of 21.7 ($SD = 3.4$). The recruitment was done by posting invitations for participation on the Andrews University campus, as well as handing out flyers and inviting students by personal invitation during class periods. Participants were offered a $15 compensation for their participation in the study. A group of 15 students also received course credit for their participation. The inclusion criteria were as follows: Students were not enrolled or had never attended any advanced biology, neurobiology, or physiological psychology courses. Subjects participated only if they had normal or corrected to normal vision by soft contacts. Subjects with glasses had to be excluded because of eye-tracking requirements.

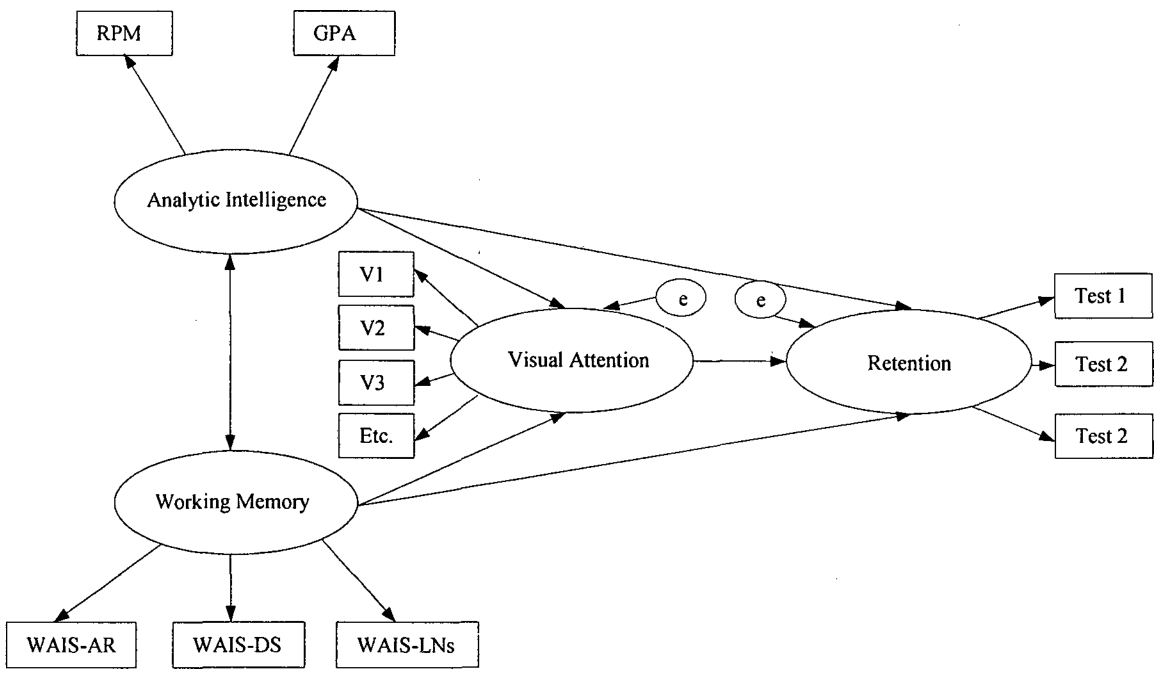
Research Questions

The following research questions guided this exploratory study:

1. Which eye-tracking variables are significant contributors in predicting retention outcomes? Based on the outcome of this question the variable(s) will be incorporated into a hypothesized model (Figure 4).

2. Will the hypothesized model be a good fit with the data?

3. Can the hypothesized model be modified on the basis of the data in order to achieve a better fit?



WAIS- AR: WAIS-III Arithmetic subscore; WAIS-DS: Digit Span; WAIS-LNs: Letter-Number Sequencing; Test 1-3: Retention tests on pain, chemical events and axons growth; V1-3: significant predictors of visual attention; RPM: Raven's Advanced Progressive Matrices Set II; GPA: self -reported GPA of student; e: error variance.

Figure 4. Hypothesized model.

Definition of Variables

The following independent variables were used in this study: Analytic intelligence, working memory, variables of visual attention, gender, and age. The dependent variable is retention. For more detailed information on variables refer to Appendix A.

Instrumentation

Analytic intelligence: Analytic intelligence was measured by the Raven's Advanced Progressive Matrices Set II (RPM). The RPM is a nonverbal test of analytic intelligence and is independent of language and thought to be largely independent of schooling (Carpenter et al., 1990; Raven, 1989). Reliability studies have shown test-retest reliability between .76 to .91 and concurrent validity tests between the Raven's Progressive Matrices, and Stanford-Binet and Wechsler show correlations usually between .70 and .80 (Carpenter et al., 1990).

Set I consisted of 12 items, whereas Set II consisted of 36 items. The items are ordered by increasing difficulty. The items are presented in a 3×3 matrix with the bottom right corner left blank. The subject is required to choose one from six possible solutions that completes the larger pattern. Set I was used for the introduction of the test and to make the participants familiar with the layout and procedure of the test. Set II was administered with a 40-minute timeframe and correct answers were summed for the final score.

Apparatus: Eye movements were recorded while the subjects studied three textbook passages that were displayed on a widescreen monitor (1600 × 900).

Eye movements were recorded by an infrared camera system known as an eye tracker (Arrington Research, Inc.; see Figure 5).

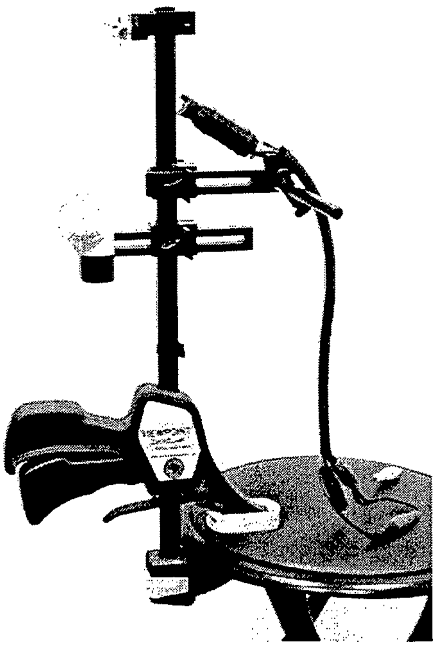


Figure 5. Eye-tracker.

Technical specifications provided by the manufacturer indicate accuracy to be approximately 0.25° - 1.0° of visual arc. Visual range is specified to be horizontally +/- 44° of visual arc and vertically +/- 20 ° of visual arc. The light used by the eye tracker is in the infrared range (940 nm), and produces 1.2 mW/cm^2 of irradiance at the eye, about the level of irradiance experienced outside in the daylight (Sliney & Freasier, 1973). Moreover, this is one tenth the accepted level for long-term exposure, and thus constituted no expected risk for subjects. Infrared light is used in the eye tracker because it is reflected by the iris and thus allows discrimination between the iris and the pupil. The table-mounted QuickClamp model was used and was positioned individually for each subject, with forehead and chin rests ensuring subjects' comfort. Eye position with respect to an image on a computer screen was located approximately 40 cm from the subject and was stored 30 times per second in a local text file. A 10-character filename was generated randomly for each subject to ensure confidentiality.

Visual Attention Variables: Visual attention is the voluntary and sustained attention to a particular place in the visual field (Steinman & Steinman, 1998). In a review of eye-tracking studies, Jacob and Karn (2003) list the following metrics which are most often reported: Overall number of fixations, gaze percentage on area of interest (AI); mean duration of fixation, overall duration of fixation, number of fixations on AI, gaze duration mean on AI, overall fixation rate (fixations/s). The previous variables are most commonly reported; however, depending on the topic and research purpose other variables might be of interest as well: scan path (sequence of fixations), number of gazes on AI, number of voluntary and involuntary fixations, and percentage of participants fixating an AI (Jacob & Karn, 2003). While the reported variables were gathered from 21 different studies on a variety of subjects, most common topics were web-based searches and military pilot studies. The following will take a closer look at eye-tracking studies and their reported variables that were found in multimedia learning. It was already previously mentioned that eye-tracking studies are very scarce where illustrations and pictures are combined (Hegarty & Just, 1993; Underwood et al., 2004).

Prior research indicated the following variables to be significant determinates of visual attention in students who are studying illustrated texts: Number and duration of fixations, reinspection (rereading elements in the same sentence during first reading), lookbacks (rereading of elements of other sentences after initial reading), sequence of inspection of AI, and attentional shifts between text and illustration. Table 1 gives an overview of five studies that have been found to use eye-tracking methods and makes comparisons between variables. The last column represents the variables used in the present study. For a more comprehensive overview of variable definitions and operationalization used in this study, refer to the Appendix.

Learning Material: Material was chosen from two biological psychology textbooks. From a pool of originally 10 passages, 3 were retained by a panel of two professors and the author. Two passages were taken from Kalat (2007) and 1 passage was chosen from Freberg (2006). The 3 passages were chosen according to the following criteria. The passages had to be understood by subjects without any prior knowledge and had to be short and related to the illustrations. Furthermore, the illustrations had to be of good quality and be relevant to the text and be easily understood.

Text readability was measured by the Flesch Reading Ease Score (FRES) (Flesch, 1948). The FRES score is calculated by a formula that takes into consideration total words, sentences, and syllables in a passage. Scores range from 0-100, with lower scores indicating more difficult content. Scores of around 30 are considered to be college-level material. FRES was calculated by the Microsoft Word readability feature. The following will give more information on the three selected expository text passages.

Table 1

Variables Used in Eye-Tracking Studies on Multimedia

		Malcom (1984)	Hegarty & Just (1993) Exp.2	Hegarty & Sims (1994) Exp. 2	Hannus & Hyönä (1999) Exp.2	Underwood, Jebbett, & Roberts (2004) Exp.1/ Exp 2	Present study
Variables	Fixations[1]	X	X	X	X	X	X
	Duration[2]	X		X	X	X	X
	Reinspection[3]				X		
	Lookback[4]		X				X
	Sequence	X					
	Response time			X		X	
	Shifts[5]	X	X		X		X
Area of Interest	Text	X	X	X	X	X	X
	Picture	X	X	X	X	X	X
	Irrelevant[6]				X		X
	Caption				X		X
Other learner variables	WM[7]						X
	Spatial ability		X	X			
	IQ[8]				X		X
Sample size		24	10	20	24	24/48	62

[1] Number of Fixations on AI. [2] Duration of fixation or gazes. [3] Reinspection of words of the same sentence during initial reading. [4] Lookbacks are rereading of previously read sentences after initial reading. [5] Attentional shifts between text and illustrations. [6] Irrelevant section, such as blank space or areas outside monitor. [7] Working memory. [8] Analytical intelligence as measured by the Raven's Progressive Matrices.

Pain: The first passage was on the topic of pain and its physiological components and neurological processes (from Kalat, 2007, pp. 209-211). The text consisted of 1,416 words and FRES was 33.1. The passage contained three illustrations that were all interpretational (Levin, 1981).

Chemical Events: The second passage was a short list of major events and sequence of chemical events at a synapse (from Kalat, 2007, p. 59). The text consisted of 213 words and FRES was 26.3. The passage contained one interpretational illustration.

Axon growth: The third passage was on the topic of axon growth and dendrites (from Freberg, 2006, pp. 138-139). The text consisted of 890 words and FRES was 28.1. The passage contained three illustrations. Two illustrations were organizational and showed sequences of axon growth. One illustration was representational and showed a picture of a growth cone.

In sum the three texts represent typical college-level reading and included a total of seven illustrations with a variety of functions (representational, organizational, and interpretational) thus representing an authentic environment of learning from textbooks.

Testing Material: Testing for retention of the studied material, the subjects were given question sheets after studying the three excerpts. The questions contained fill in the blanks, multiple choice, and short answers and were taken from the test bank that accompanied the textbooks. Table 2 shows the test questions according to three characteristics. First, the three passages were on the topic of pain (23 questions), chemical events (16), and axon growth (21). Type of question distinguishes between factual knowledge and conceptual questions. Relation indicates if the information required to answer the question was found in the text, the illustration, or in both. The three test sheets contained a total of 60 questions.

Table 2

Test Question Characteristics

	Type		Relation			Total
	Conceptual	Factual	Text	Illustration	Both	
Pain	4	19	14	3	6	23
Chemical Events	5	11	5	2	9	16
Axon	7	14	14	1	6	21
Total	16	44	33	6	21	60

Working Memory: WM was assessed by the working memory index score of the Wechsler Adult Memory Scale, third edition (WAIS-III). The following subtests were used to compute the score: Arithmetic (A), Digit Span (DS), and Letter-Number Sequencing (LNs). Test-retest reliabilities for these subtests have been reported to range from .70s (DS, LNs) to .80s (A). Interscorer reliabilities are reported to be in the low .90s (Hess, 2001). Criterion-related validity studies show that WAIS-III scores correlate in the high .70s and .80s with other intelligence tests such as the Stanford-Binet (Hess, 2001; Rogers, 2001). Content validity was also supported by a panel of experts who reviewed the WAIS-III (Rogers, 2001). Reviews by Hess (2001) and Rogers (2001) report the

WAIS-III to be the primary instrument for clinicians and researchers to assess adult intelligence.

Data Collection

Procedure: The subjects were tested individually in a computer lab. Initially they were given the RPM Set II to test for analytic intelligence. There was a time limit of 40 minutes to complete 36 questions. Thereafter the three memory subscales of the WAIS-III were administered to test for working memory ability (approximately 20 min total). There was a short break before the eye-tracker was fitted and calibrated with a 36-point-grid. The participants were asked to keep their head still during the experiment and were given one textbook passage at a time (the sequence of the passages was selected at random). They were instructed to study the content carefully in order to answer questions on a short test. There was no time limit to study the text; however, most participants read the text passages in 10–15 min. After each passage they were given the retention test on the topic (no time limit). Before showing the next passage the eye-tracker was again calibrated with a 36-point-grid. The total time for eye-tracking and retention testing was approximately 60 min. Total time for the entire study was about 2 hours.

Scoring

RPM test sheets were scored according to the test manual. Correct answers were given a score of 1, wrong answers a score of 0. The sum of all correct answers was used as the final RPM score. WAIS-III subtests were scored according to the manual and total scores were used as measures of the variable. Retention test sheets were scored according to the solutions provided in the test bank. Total scores of each test were used in further analysis.

Data Analysis

Multiple linear regression (MLR) was used in order to determine which eye-tracking variables are significant contributors to retention which will in turn be incorporated into the model.

Structure Equation Modeling (SEM) was applied to test for the hypothesized model (Figure 4). SEM is an ideal statistical tool to test and refine theoretical models especially in the context of multivariate social or behavioral phenomena. SEM does not exclude simple analyses such as *t*-tests, ANOVA's or regressions, but opens the possibilities to multilevel analyses. Buhi, Goodson, and Neilands (2007) list four advantages of SEM. First, multivariate methods best explain behavioral models in which several causes and effects happen at the same time. Multivariate analysis thus best resembles reality. Second, SEM controls for Type I errors, which is an advantage over univariate tests which inflate the error if multiple tests are run on the same data. Third, hypothesized models with direct or indirect effects can be tested by empirical models. The theoretical models can be represented visually and are thus more intuitive and understood more easily. Fourth, SEM controls for measurement error and encompasses techniques to deal with missing cases.

There are, however, disadvantages with SEM. The most important one is the need of larger sample sizes (Meyers et al., 2006). Another caution of SEM use is the correlational nature of the analysis, thus excluding cause and effect conclusions.

The hypothesized model was tested against the empirical model by comparing covariance matrices of the hypothesized model with the empirical model according to three categories and five fit measures:

Absolute measures: Chi-square (χ^2), goodness-of-fit index (GFI), and root mean square error of approximation (RMSEA).

Fit measures: Comparative fit index (CFI).

Parsimonious fit measures: Parsimonious goodness-of-fit index (PGFI).

Budget

This research was partly supported by the Andrews University Faculty Research Grant given to Drs. Karl G. Bailey and Rudolph Bailey. Included in the grant was a $15 compensation for the subjects' participation, amounting to a total cost of $930. Additionally the test materials for the RPM and WAIS-III were funded by the grant.

CHAPTER 4

RESULTS

This chapter presents the results of the procedures outlined in chapter 3 in order to test the research questions. Initially, data were screened for violations of assumptions, and descriptive statistics of the variables are presented. Thereafter the three research questions are addressed individually.

Data Screening and Descriptive Statistics

This study contained 19 variables (for a more detailed description of the variables refer to Table 8): Ravens Progressive Matrices total score (RPM); memory subscales of WAIS-III on arithmetic (WAIS-AR), digit span (WAIS-DS), and letter-number sequencing (WAIS-LNs); total time spent reading text (totalTime); proportion of time spent on text (propTimeTXT), illustrations (propTimePIC), captions (propTimeCAP), and irrelevant sections (propTimeIRR); number of fixations in text (numberFixationsTXT), illustrations (numberFixationsPIC), captions (numberFixationsPIC), irrelevant sections (numberFixationsIRR); attentional shifts between text and illustrations (shifts); number of look-backs to same area (lookbacks); scores of retention tests on pain (test 1), chemical events (test 2), axon growth (test 3), and total score of all three tests (total test).

Prior to all analysis the data were screened for violations of assumptions. Since the design of the study is correlational, the data were tested for violations of both normality and linearity assumptions.

All variables were found to be within acceptable limits of skewness and kurtosis (±1) except the following variables exceeded the limit: WAIS-LNs, propTimeTXT, propTimeIRR, and numberFixationsIRR. Shapiro-Wilk tests of normality did not find any violation of assumptions with a stringent alpha of .001 for the first two variables; however, the last two variables showed severe negative L-skewness. A base-10 logarithm transformation was done on numberFixationsIRR and was named numberFixationsIRRlg10. A square root transformation was done on propTimeIRR and was named propTimeIRRsqrt. After transformation all variables were within acceptable limits of skewness and kurtosis. Furthermore, tests of normality were all non-significant except for propTimeIRRsqrt. However after analyzing Q-Q plots and since skewness and kurtosis were good, the variable was deemed to be acceptably normally distributed.

Nine univariate outliers were detected (1 for WAIS-LNS, 1 for propTimeTXT, 1 for propTimeCAP, 2 for propTimeIRRsqrt, and 4 for totalTime), none of which were considered extreme or unusual enough for deletion. Furthermore most of the variables were less than 2% of the sample and thus included. The four outliers in totalTime were an exception and were analyzed individually. These four outliers represented subjects who took longer to read the three passages (about two times longer than the average). The outliers were deemed meaningful and were not deleted. Mahalanobis distances were computed to screen for multivariate outliers, but none were detected (p>.001). The data set contained no missing values.

The linearity assumption was tested by investigating pairwise scatterplots and examining residual scatterplots, both of which did not show any evidence of violations of linearity assumption. The following will now describe the variables in more detail.

The sample consisted of 62 college students from Andrews University (26 males, 36 females) with an average age of 21.7 (*SD* = 3.4) years. Average scores (Table 3) on the Raven's Advanced Progressive Matrices showed a mean of 22.4 points (*SD*=4.95), which according to reported norms is considered to be in the 57th percentile for U.S. adolescents aged 18-32 (Raven, Raven, & Court, 1998). Higher scores were expected since the sample consisted of college students. In a study (Bors & Stokes, 1998) with a representative sample of first-year college students, mean scores for the RPM Set II (40 min time limit) are reported to be 22.14 (*SD*=5.6). The scores in this sample are thus representative of a college population.

Average raw scores on the subtests of the Wechsler Adult Intelligence Scales were as follows WAIS-AR (*M*=13.8, *SD*=3.39), WAIS-DS (*M*=17.4, *SD*=4.13), and WAIS-LNs (*M*=11.9, *SD*=3.54). Only raw scores are reported since the conversion into scaled scores did not differ for the age range in this sample. According to the scoring manual (Wechsler, 1997) sums of the scaled scores for the three memory subscales achieved a working memory index of 104, which represents a 61st percentile. Again higher working memory was expected since the sample consisted of students. Longman, Saklofske, and Fung (2007) developed normative samples by education level for the WAIS-III. Mean scores for subjects with 13-15 years of education in the U.S. are reported to be 104.1 (*SD*=15). Thus working memory scores in the current sample are representative of a college population.

Table 3

Means and SDs for Age, Intelligence, and Memory Scores (Raw Scores)

	Mean	*SD*
Age	21.7	3.4
RPM	22.4	4.95
GPA	3.5	.38
WAIS-AR	13.8	3.39
WAIS-DS	17.4	4.13
WAIS-LNs	11.9	3.54

Note. $N = 62$.

Retention test scores are shown in Table 4. On average subjects scored 16.2 (*SD*=4.04) on items testing for retention on the passage on Pain. Average scores on Chemical events were 6.8 (*SD*=3.1), whereas on axon growth average scores were 14.6 (*SD*=3.5).

Table 4

Raw Scores on Retention Tests

	Mean (Max)	*SD*
Pain	16.2 (23)	4.04
Chemical Events	8.6 (16)	3.1
Axon Growth	14.6 (21)	3.5
Total	39.4 (60)	9.2

In sum, the subjects participating in this study are representative of a college population in terms of analytic intelligence and working memory. Furthermore the data set did not contain any missing values and after transformations on two variables, all variables supported the normality assumption. Pairwise linearity was deemed satisfactory and only a few outliers were detected, none of which were deleted.

Research Question 1

In order to determine which eye-tracking variables are significant predictors of retention, a Multiple Linear Regression (MLR) was run. To check for violations of assumptions bivariate correlations were analyzed between the following 11 predictor variables: propTimeTXT propTimePIC propTimeCAP, propTimeIRRsqrt, numberFixationTXT, numberFixationsPIC, numberFixationsCAP, numberFixationsIRRlg10, totalTime, Shifts, and Lookbacks.

Table 5 shows that there were several instances of collinearity ($r > .70$). Collinearity can cause problems with analysis of MLR (Meyers et al., 2006) and indicates that two variables are measuring similar constructs. In order to limit collinearity some variables were combined. Both variables measuring proportion and fixations on irrelevant sections showed a correlation of .806. These two variables were summed into a variable that accounts for error of eye tracking and measures attention on irrelevant sections and was named 'IRR'. Furthermore, number of fixations on text, illustration, and caption, as well as measures of shift of attention and lookbacks showed high correlations ranging from .593 to .917. Research (e.g., Hyönä & Nurminen, 2006) has shown that lookbacks are indicative of a strategy of topic structure learners. Other research shows evidence that frequency of fixations on illustration is indicative of mental model building (e.g., Hegarty et al., 1991). Shifts between illustration and text and lookbacks have also been found to be indicative of a learning strategy of successful learners (e.g., Hannus & Hyönä, 1999).

The results from previous research and the high correlations between the variables are evidence that the five variables are measuring a similar construct. The five variables were thus summed into the variable 'Analysis', representing a measure of mental model construction and thoroughness of analysis.

Bivariate correlations containing the two new variables (IRR, Analysis) as well as the remaining four variables (propTimeTXT, propTimePIC, propTimeCAP, totalTime) showed no evidence of collinearity; all correlations were below .70 (Table 5). For descriptive statistics on these variables see Table 10.

Table 5

Correlations Among New Eye-Tracking Variables

	propTimeTXT	propTimePIC	propTimeCAP	totalTime	IRR	Analysis
testTOTAL	.002	.320*	.150	.084	-.166	-.064
propTimeTXT		-.596**	-.271*	-.255*	-.420**	-.521**
propTimePIC			.212	.406**	.223	.207
propTimeCAP				.204	-.160	-.008
totalTime					.385**	.656**
IRR						.653**

* $p<0.05$. ** $p<0.01$.

In sum, after initial analysis, collinearity was detected among several of the 11 predictor variables. Variables two and five were combined to form new variables (IRR, Analysis). Thus for MLR analysis the following six predictor variables were used: propTimeTXT, propTimePIC, propTimeCAP, totalTime, IRR, and Analysis. The total score of the three tests (testTotal) was used as the criterion variable.

Multiple *R* for regression was statistically significant $F(6,55) = 2.546$, $p=.03$, $R=.466$, R^2 *adj* = .132. However, only propTimePIC was a significant contributor to testTotal ($p<.05$). All five other variables did not reach significance level ($p>.05$). PropTimePIC showed a bivariate correlation of .32 with testTotal and a semipartial correlation of .392, also β weights (.605) were highest for that variable. See Table 6.

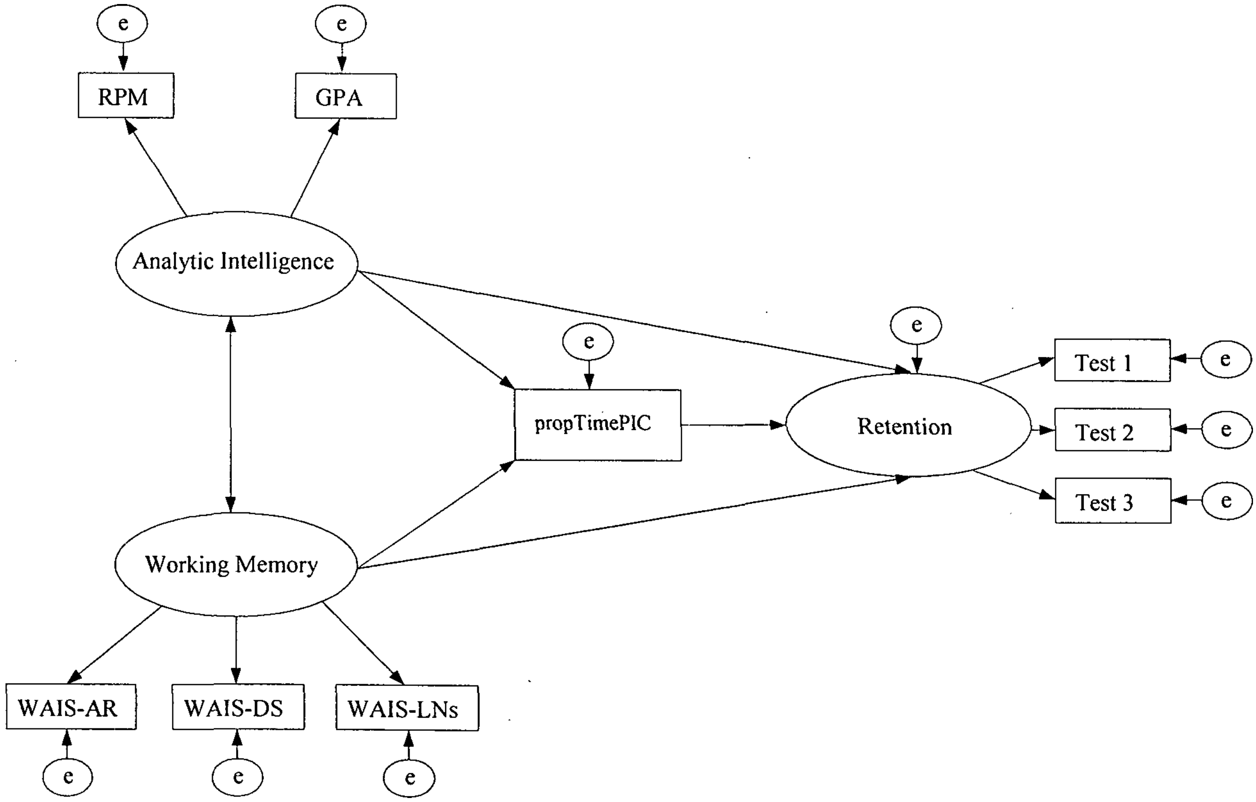
Table 6

Multiple Regression Coefficients

	Standardized Coefficients			Correlations	
	Beta	*t*	Sig.	Bivariate	Semipartial
propTimeTXT	.414	1.943	.057	.002	.232
propTimePIC	.605	3.285	.002	.320	.392
propTimeCAP	.140	.994	.325	.150	.119
totalTime	-.198	-.955	.344	.084	-.114
IRR	-.230	-1.396	.168	-.166	-.167
Analysis	.308	1.258	.214	-.064	.150

Note. $R= .466$, $R^2= .217$, R^2 *adj*= .132 (N=62, p=.03).

Research question 1 was concerned with establishing significant contributors of eye-tracking variables to retention. Only one variable was found to be a predictor: proportion of time spent on illustrations. Based on these findings, the variable propTimePIC was introduced into the hypothesized model from Figure 4. The thus newly created model can be seen in Figure 6.



WAIS- AR: WAIS-III Arithmetic subscore; WAIS-DS: Digit Span; WAIS-LNs: Letter-Number Sequencing; Test 1-3: Retention tests on pain, chemical events and axons growth; V1-3: significant predictors of visual attention; RPM: Raven's Advanced Progressive Matrices Set II; GPA: self reported GPA of student; e: error variance; propTimePIC: proportion of time spent on picture.

Figure 6. New hypothesized model.

Research Question 2

The hypothesized model was evaluated via AMOS 16.0 using the following indices: chi-square (χ^2), goodness-of-fit index (*GFI*), root mean square error of approximation (*RMSEA*), comparative fit index (*CFI*), and parsimonious goodness-of-fit index (*PGFI*). Chi-square values can be inflated by sample size; however, for small sample sizes such as in this research, it has been proposed that chi-square is the most adequate measure of fit (Kenny, 2008). Values for *GFI* and *CFI* can range from .00 to 1.0, with values of >.90 indicating adequate fit and values of >.95 indicating excellent fit (Hu & Bentler, 1999). RMSEA statistics takes into account the error of approximation in the population (Browne & Cudeck, 1989) with values ranging from .00 to 1.0 and values closer to 0 indicating good fit. Byrne (2001) judges values of <.05 as indication of good fit and values of <.10 as indication of adequate fit. PGFI values also range from .00 to 1.0 with values >.50 indicating adequate fit (Meyers et al., 2006). In addition to judging the fit of the model, path coefficients were assessed for statistical significance at $p<.05$. The model contained 22 variables, of which 9 were observed. There were 12 exogenous and 10 endogenous variables.

Results are summarized in Table 7 and showed no difference between the hypothesized and the empirical model with a nonsignificant chi-square $\chi^2(22, N=62) = 24.508, p>.05$. Goodness-of-fit indices were adequate (*GFI* = .923) and *CFI* was excellent (.986). Also the *RMSEA* was good at .043; only *PGFI* was low at .451. All of the above measures support the hypothesized model's fit. Most importantly chi-square was nonsignificant which supports the interpretation of the hypothesized model's excellent fit to the data and metric invariance.

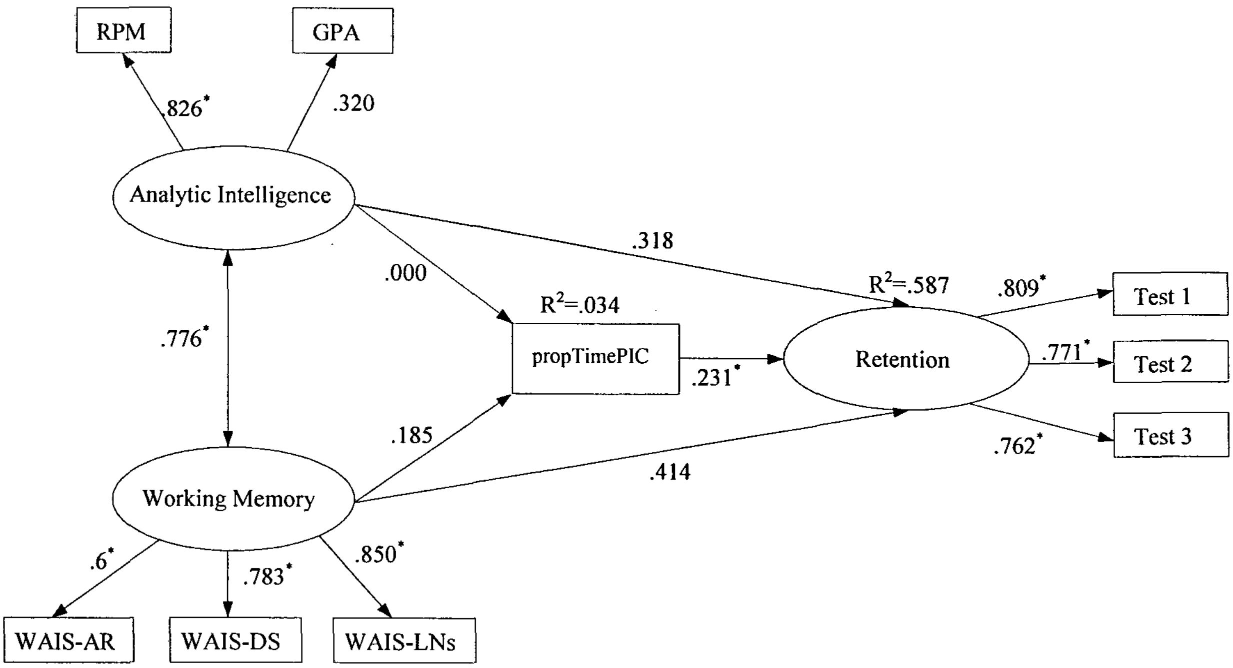
Table 7

Fit Measures

Absolute		Relative		Parsimonious	
Test	Value	Test	Value	Test	Value
χ^2	.321	*CFI*	.986	*PGFI*	.451
GFI	.923				
RMSEA	.043				

Results for the path analysis are summarized in Figure 7. Not all path coefficients reached significance ($p<.05$). Interestingly, the only significant predictor of retention is the visual attention variable (.231), whereas the other two predictors (analytic intelligence, working memory) did not reach significance. The fist endogenous variable, propTimePIC, showed only limited amount of variance explained (.034); however, the second endogenous variable, retention, demonstrated a strong measure of explained variance of .587.

The results of the SEM support the theory that learner characteristics are important factors in multimedia learning. In this sample working memory and intelligence have a direct influence on retention and are not mediated by an eye-tracking strategy; however, the relationships did not reach significance. The model supports the



*p<.05.

WAIS- AR: WAIS-III Arithmetic subscore; WAIS-DS: Digit Span; WAIS-LNs: Letter-Number Sequencing; Test 1-3: Retention tests on pain, chemical events and axons growth; V1-3: significant predictors of visual attention; RPM: Raven's Advanced Progressive Matrices Set II; GPA: self reported GPA of student;; propTimePIC: proportion of time spent on picture.

Figure 7. Structure and measure coefficients.

theory of subjects, with adequate learning strategies benefit most from a multimedia context. In particular the only significant determinant of learning strategy and retention was proportion of time spent fixating illustrations.

Research Question 3

The last research question on how to ameliorate the model has become obsolete since the previously discussed results showed near perfect fit between hypothesized model and empirical data. Thus, modifications and adjustments to the model were not necessary.

CHAPTER 5

DISCUSSION

This exploratory study is one of a few, linking basic research with application to education. Research on multimedia learning has become abundant in the last few decades, however, little has been done to test results and principles in a more authentic situation. Furthermore, many variables have been found to interact and influence learning in a multimedia context. In particular, learner characteristics have recently emerged as vital predictors for learning outcomes. This research has focused on such learner characteristics and tested them in an authentic learning environment. Thus the results not only add to the knowledge and research, but important implications for practice can be derived as well. Before discussing the findings and presenting implications for practice, a short summary of the results (chapter 4) will be given.

Results to the first research question of significant predictor variables of retention for eye-tracking variables found only one variable to be a significant contributor. From originally six variables, only proportion of time spent on illustrations was retained as predictor of retention. The second research question tested a model of multimedia learning (Figure 6) by means of Structural Equation Modeling. Results support the hypothesized model and indicate a good fit between the model and the empirical data.

This study tried to understand the effects of cognitive ability, working memory, and visual attention on processing illustrated texts, thus trying to understand what makes successful and unsuccessful learning with textbooks. In short, it can be said that learner characteristics play an important role in multimedia learning, and there is also evidence that learnable and teachable strategies influence outcomes in an essential way.

In order to determine subjects' attentional direction, eye-tracking methodology was used. Measuring visual attention is quite popular and widely used in cognitive psychology, however, only very few studies have used it in combination with text and illustrations. It is thus not evident which variables offer valuable information on visual attention in that context. This study found that several commonly measured variables were highly correlated. Variables that were reported to classify elementary children do not seem to distinguish in a college population with cognitively advanced individuals. For instance, look-backs to already read passages and attentional shifts between text and picture have been reported to distinguish between successful and unsuccessful elementary learners (Hannus & Hyönä, 1999). In this study these two variables have failed to show any significance in predicting learning outcomes. There are, however, also similarities. One such parallel was the heavy reliance of learners on text, with illustrations being only marginally inspected. It is thus interesting that the proportion of time spent on illustrations was the only significant predictor of retention. In previous research, a more elaborate inspection of pictorial information has been reported to be a characteristic of successful adult learners (Schnotz, Picard, & Hron, 1993). Moreover, this result is precisely what theories of multimedia learning have predicted. Schnotz (2005) hypothesized in ITCP that for low prior-knowledge students, illustrations should prove to be of more importance in generating a mental model than for high prior-knowledge learners. Since the sample in this study consisted only of low prior-knowledge students this prediction was supported, since students who took advantage of studying illustrations clearly showed learning benefits. Similarly, CTML (Mayer, 2005b) agrees that illustrations code information in two channels which help construction of an integrated mental model. The results from the first research question thus clearly support the theories of multimedia learning and their indication of the importance of illustrations for low prior-knowledge students in building mental models.

Furthermore, the results suggest that learning strategies differ according to age and level of schooling. It can be assumed that learning strategies and reading have reached more advanced levels with college students and thus less between-subject differences should be found in terms of learning abilities. Nevertheless, research on text only reading strategies has found at least two different reading strategies in college students who were named linear readers and topic structure learners (Hyönä et al., 2002). There is evidence in this research that there are distinctly different strategies in studying illustrated text as well. Proportion of time spent on illustrations (propTimePIC) is negatively correlated with proportion of time spent on text (propTimeTXT). In general, students heavily rely on text with on average spending 66% (*SD*= 7.8%, Table 10) of the time on text. Yet, there is a difference among students in how long they look at illustrations. Time spent on illustrations range from 1% to 28% (*M*= 16.3%, *SD*=5.4). Time spent on text is not only negatively correlated with time spent on illustrations (-.596, Table 9) but also with total time (-.255) and analysis of the text (-.521). These findings are an indication that there is a range of strategies of studying illustrated text. While there are many variations, there seem to be two groups at the ends of a continuum that could be described as follows. One group of subjects relied on text rather than on pictures and read through the text relatively quickly with little inspection of illustrations and less thorough analysis. Another group indicated applying a strategy that incorporated illustrations, spending more time integrating different pieces of information, and generally showing a more detailed analysis of the content. These descriptions of strategies are only tentative and only through future research can these findings be validated. Little research has been done investigating global strategies of reading, and this study indicated that such research is warranted and would prove to be beneficial.

Studies on phenomena that incorporate a variety of variables have limitations if they are studied individually. Multivariate methods best explain behavioral models in which several causes and effects happen at the same time and thus best resemble reality (Buhi et al., 2007). Structural Equation Modeling (SEM) is an ideal statistical tool to test and refine theoretical models especially in the context of multivariate social or behavioral phenomena. With the second research question this study tested a hypothesized model of multimedia learning. Research on multimedia learning acknowledges that not only the nature of the presented material, but also learner characteristics play an important role in multimedia learning (e.g., Gyselinck & Tardieu, 1999; Peeck, 1987; Winn, 1987). Intellectual ability is one of these variables that has been investigated and has proven to generate contradictory findings. Several studies investigated whether low-ability students or high-ability students benefit more from illustrated text (e.g., Hannus & Hyönä, 1999; Koran & Koran, 1980; Reid & Beveridge, 1990). It seems that, in general, low-ability elementary students benefit more than their high-ability peers (for more a more detailed discussion see chapter 2). However, the reported studies investigating intellectual ability have used subjects aged 10-16 and not much is known about college-aged students.

Several theories of multimedia learning (e.g., ITPC, CTML, dual coding) stress the limitations of working memory thus demonstrating the crucial role of working memory during learning. Yet, there is no research that tested working memory capacity in relation with text and illustrations. Again, the only research that tested for working memory and related it to visual attention stems from studies that were concerned with text-only contexts (e.g., Hyönä et al., 2002). To my knowledge there is no research that took working memory into consideration that investigated text and illustration.

This research incorporated three variables that have found little to no attention in multimedia research. Working memory capacity, intellectual ability, and visual attention were included in a hypothesized model of learning. All three variables were used as predictors of retention, and intercorrelations between the predictors were also included. Thus, combining the variables and hypothesizing relationships between variables in one model made it possible to test the entire construct simultaneously. This approach of testing a model is another advantage of this research that has never been done before in the context of multimedia learning.

The current results suggest that the hypothesized model is an excellent fit to the data, thus indicating that learner characteristics have an influence on learning in multimedia settings. Three predictors of retention were tested: memory, analytic intelligence, and visual attention to illustrations. Out of the three, only visual attention to illustrations proved to be a significant predictor. Memory and analytic intelligence showed medium correlations but did not reach significance. This is probably a direct influence from the limitation of the sample size. This study contained one of the largest samples that were ever reported in eye-tracking studies (N=62). Nevertheless, the large sample size in terms of eye-tracking studies is still at the lower range for SEM. In future research with higher sample sizes these correlations might reach significance.

Analyzing the remaining path coefficients proved to be equally interesting. Analytic intelligence and working memory showed little to no correlation to visual attention on illustrations and thus show no indirect influence on retention. These results are interesting since in previous research visual attention is reported in combination with other learner characteristics. For instance, Hannus and Hyönä (1999) report high-ability students to make more shifts and lookbacks than low-ability students. Similarly, Hegarty and colleagues (Hegarty & Just, 1993; Hegarty & Sims, 1994) report different visual attention for high mechanical-ability students and low mechanical-ability students. The current results cannot be directly compared to these findings. The study by Hannus and Hyönä investigated elementary children only and the authors admit that the differences might not be confounded with intelligence but rather with reading ability. The studies by Hegarty did not control for prior knowledge and were very specific to physical systems. The current results show that there is no relationship between intellectual ability and how advanced and experienced learners study textbook passages. Visual attention on text seems to be a learned characteristic and not dependent on intellectual ability. This finding is of great importance and is further discussed in the implications for practice.

In sum, there is evidence that there are different reading strategies of illustrated text in a college population. The strategies differed mainly in how subjects allocated time on illustrations, which proved to be the only significant predictor for retention. Results from SEM are the first of a kind and even though it contained one of the largest sample sizes reported for eye-tracking studies, it was still limited and a few coefficients did not reach significance due to that limitation. Nevertheless, the results showed good support for the influence of learner characteristics on retention with proportion of time spent on illustrations again being the only significant predictor for retention. Furthermore, the findings suggest that this is an acquired reading strategy and is not dependent on abilities such as intelligence or working memory. These results support several implications for research and for practice and are discussed in the following paragraphs. First the limitations are discussed.

Limitations

As was previously mentioned, there is a strong limitation in the sample size of this study. As a result, a few path coefficients did not reach significance.

The lack of previous research in multimedia learning using eye-tracking methodologies and SEM made formulating predictions and hypotheses difficult. Thus, this research used an exploratory setup which limits the applicability of results to practice but still holds important implications and directives for future research.

The sample consisted of college students and thus inferences on a larger population are not warranted. However, the sample was representative of a college population in terms of intelligence and working memory. The results are thus applicable to advanced and experienced learners.

While research has shown that there are several ways to test for learning and understanding of material, this research tested mainly for immediate retention and did not test knowledge in application or long-term learning. While testing only for short-term retention is limited, it is nevertheless common and widely used in practice. While the results might be limited in adding knowledge to the already existing basic research literature, it might hold more relevance for practical implications. The test questions were taken from a test bank and it is assumed that many teachers using the textbooks administer similar tests as this study has.

Another limitation of this study is in reference to the incentive to do well in the retention tests. The sample in the study did receive a financial incentive to participate; however, the compensation was not linked to the outcome of the retention tests. These results thus do not necessarily reflect authentic college learning.

Implications

Research

The previously mentioned limitations and the results of the study leave room for future research. Only a very few studies used eye-tracking methods to test visual attention with text and illustrations (e.g., Hannus & Hyönä, 1999; Hegarty & Just, 1993; Hegarty & Sims, 1994). There is little evidence regarding to which variables visual attention is measured. While this research has shown that proportion of time spent on illustration is a significant contributor to retention, only by more researchers publishing results and using eye-tracking methodologies will these findings prove to be of meaning. Similarly, only limited research is available on global strategies on reading text (e.g., Hyönä & Nurminen, 2006). To my knowledge there is no research on strategies in reading illustrated text. The current study indicates that there are different ways to direct visual attention in a multimedia context, but more research needs to be done in order to establish strategies of learning in multimedia contexts.

The major limitation of this study is the small sample size in terms of SEM. Even though it is to date one of the largest studies on eye-tracking, only future research with larger sample sizes will be able to shed more light on an intriguing multivariate interaction of learner characteristics. The hypothesized model used in this study has proven to be useful and meaningful. However, several path coefficients did not reach significance. For future research, the model should prove to be of value as a reference and more studies should investigate adequate fit of the current and similar models of learning.

Research would also benefit if studies were to investigate learning by not only testing for retention but also testing application of the learned material as well as measuring long-term learning effects. These factors could be incorporated in a revised model in future research.

Furthermore, even though this research is one of a few that have utilized an authentic learning environment, little incentive was given to do well. Future research could try comparing results if students were tested where results either have financial or educational (i.e., grade) benefits for the individual.

Practice

There is one major implication for practice that can be derived from this study. There seem to be different strategies or ways to study academic expository texts. Secondary teachers and even tertiary teachers should spend time to discuss ways to study difficult text. Theories on multimedia learning stress the importance of mental model construction (e.g., Gyselink & Tardieu, 1999; Hegarty & Just, 1993; Mayer, 2002;

Schnotz, 2005). While the importance of text in learning is evident in this research as well as in others (e.g., Hannus & Hyönä, 1999), there is great variance in how students utilize illustrations in constructing mental models. This research has shown that the proportion of time spent looking at illustrations enhances mental model construction and thus better retention. These results should encourage teachers to spend time with students on how to extract pertinent information from illustrations and how information in both text and illustrations can be used to understand scientific texts. For instance, asking Why and What questions on illustrations can be useful (Carney & Levin, 2002). Students on the other hand should be encouraged by these results that even though study time is often limited, studying, analyzing, and integrating information from illustrations is time well spent.

APPENDIX: TABLES

Table 8

List of All Variables Used in the Study

Variable	Conceptual definition	Instrumental Definition	Operational Definition
Analytic intelligence	Analytic intelligence is the ability to form perceptual relations and independent analogies, solve problems involving new information without relying extensively on previous knowledge.	**RPM***: Raven's Progressive Matrices is a nonverrbal test of analytic intelligence. Items consists of a 3 x 3 matrix with one entry missing (bottom right) and eight multiple choices to complete the matrix. Set II of Advanced Progressive Matrices was used and consists of 36 items. Total score on the test was used for the variable.	RPM: 0-36
Working Memory	Working memory capacity. A short term memory store limited in time and capacity.	Standardized test: Memory subtest from Wechsler Adult Memory Scale – III (WAIS-III). **WAIS-AR**: Arithmetic **WAIS-DS**: Digit Span **WAIS-LNs**: Letter-Number Sequencing	WAIS-AR: 0-22 WAIS-DS: 0-30 WAIS-LNs: 0-21
Gender	Gender of the subject	Male, Female	Gender: Male = 1, Female = 2
Age	Age of the subject	Number of years that person has lived since date of birth.	Age: 0-100 years
Time	Measure of time spent on area of interest (AI)	Eye-tracking data provided measures on the following AIs: Text, illustrations, captions, and irrelevant sections. **total Time**: total time in seconds across all three passages **propTimeTXT**: proportion of time spent on text compared to total time. **propTimePIC**: proportion of time spent on illustrations **propTimeCAP**: proportion of time spent on captions. **propTimeIRR**: proportion of time spent on irrelevant sections	totalTime: 0 – 1800 s propTimeTXT: 0-1 propTimePIC: 0-1 propTimeCAP: 0-1 propTimeIRR: 0-1

Table 8--*Continued.*

Variable	Conceptual definition	Instrumental Definition	Operational Definition
Fixations	Total number of fixations (times where eye is essentially stationary).	Eye-tracking data. Number of fixations made on the following AIs: Text, illustrations, captions, and irrelevant sections. Fixations below 250ms on text and fixations below 100ms on illustrations, captions, and irrelevant sections were ignored. **numberFixationsTXT**: number of fixations on text **numberFixationsPIC**: number of fixations on text **numberFixationsCAP**: number of fixations on text **numberFixationsIRR**: number of fixations on irrelevant sections.	numberFixationsTXT: 0-7200 numberFixationsPIC: 0-18000 numberFixationsCAP: 0-18000 numberFixationsIRR: 0-18000
Shifts	Number of attentional shifts between AI	Eye-tracking data. Number of **Shifts** between text and illustration and between illustration and text.	Shifts: 0 – 1000 (?)
Lookbacks	Lookbacks are defined as attentional shifts to areas that have already been looked at	**lookback**: Lookbacks are measured according to how many times the same part of a 10 by 18 grid was re-fixated.	lookback: 0-1000 (?)
Retention	Measure of retention of studied material	Retention is tested on three tests. Items test for factual knowledge and conceptual understanding. **Test 1**: Pain **Test 2**: Chemical Events **Test 3**: Axon growth	Test Total: 0-60 Test1: 0-23 Test 2: 0-16 Test 3: 0-21

*Bold typeface indicates name of variable as it appears in tables.

Table 9

Correlations Among Eye-Tracking Variables

		Proportion of Time				Fixations						
		TXT	PIC	CAP	IRR	TXT	PIC	CAP	IRR	totalTime	Shift	Lookback
	Test^{+}	.002	.320*	.150	-.212	.010	.084	.053	-.160	.084	-.110	-.080
Proportion	TXT		-.596**	-.271*	-.322*	-.310*	-.620*	-.282*	-.422**	-.255*	-.448**	-.545**
	PIC			.212	.162	.062	.540**	.325**	.225	.406**	.236	.167
	CAP				-.273*	-.073	.129	.457**	-.148	.204	-.057	-.010
	IRR					.432**	.415**	.099	.806**	.180	.448**	.481**
Fixations	TXT						.760**	.595**	.593**	.598**	.779**	.917**
	PIC							.609**	.616**	.716**	.869**	.854**
	CAP								.288*	.714**	.530**	.588**
	IRR									.396**	.597**	.659**
totalTime											.626	.620**
Shifts												.882**

*. 0.05 level. **. 0.01 level. $^{+}$Total score on retention tests.

Table 10

New Eye-Tracking Variables – Descriptive Statistics

	Minimum	Maximum	Mean	*SD*
propTimeTXT	.350	.807	.661	.078
propTimePIC	.043	.279	.163	.054
propTimeCAP	.014	.098	.045	.018
timeTOTAL	506.33	2189.17	1202.91	356.63
Shifts	148.00	1086.00	508.08	223.95
Lookbacks	378.00	2890.00	1558.68	689.80
IRR	.00	1.53	.650	.397
Analysis	826.00	4982.33	2767.156	1108.06

Note. *N*= 62.

Table 11

Correlations Among Memory, Intelligence, and Retention Scores

		Memory		Intelligence		Retention		
		DS	LNs	GPA	RPM	Pain	Chemical	Axon
Memory	A	.475**	.468**	.271*	.488**	.316*	.342**	.363**
	DS		.684**	.183	.447**	.388**	.433**	.464**
	LNs			.165	.552**	.538**	.397**	.461**
Intelligence	GPA				.264*	.256*	.217	.059
	RPM					.548**	.387**	.331**
Retention	Pain						.607**	.597**
	Chemical							.633**

*$p < .05$. **$p < .01$.

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