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The effect of leads on cognitive load and learning in a conceptually rich hypertext environment

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Abstract

The purpose of this experiment was to determine whether leads affect cognitive load and learning from conceptually rich hypertext. Measures of cognitive load included self-report of mental effort, reading time, and event-related desynchronization percentage of alpha, beta, and theta brain wave rhythms. Conceptual and structural knowledge tests, as well as a recall measure were used to determine learning performance. Measures of learners' reading ability, prior knowledge, and metacognitive awareness were employed to establish the effect of individual differences on cognitive load and learning from traditional and lead-augmented hypertext. Results demonstrated that while leads appeared to reduce brain wave activity associated with split attention, processing of redundant information contained in hypertext nodes may have increased extraneous cognitive load, and decreased germane load that is required for learning to take place. Whereas the benefits of leads relative to cognitive load and learning may have been mediated by the redundancy effect, learners with better developed metacognitive skills tended to use leads as a tool to review information in the linked nodes while revisiting content in the primary text passage. Limitations of the currently available cognitive load measures are discussed as applied to direct assessment of this theoretical construct.

Introduction

Educational research describes hypertext as a tool that encourages independent self-regulated learning and allows learners to create deep conceptual understandings of a knowledge domain (e.g., Jonassen, 1989; Spiro & Jehng, 1990). Yet, some scholars argue that certain features of hypertext may in fact increase cognitive load and inhibit learning (e.g., Niederhauser, Reynolds, Salmen, & Skolmoski, 2000; Rouet, Jarmo, Dillon, & Spiro, 1996). In this chapter the research problem is situated relative to the structure of hypertext and cognitive processes involved in learning from hypertext. Cognitive load theory is discussed as the theoretical framework that guides the research questions of this study.

In 1945 Vannevar Bush introduced the notion of a *memory extender* or *Memex* – a microfilm-based device that could help people organize the ever growing amounts of information. The device would be mechanized so that it could be consulted with exceeding speed and flexibility. Bush predicted that “wholly new forms of encyclopedias will appear, ready made with *a mesh of associative trails running through them*, ready to be dropped into the Memex and there amplified” (Bush, 1945, p. 102; emphasis added). This vision of a linked information system preceded the development of digital hypertexts by nearly 35 years. During the intervening years the reality of effective information organization systems has developed considerably. Digital technologies have provided a means for presenting information in the form of a hypertext – a computer-based presentation system where all information is organized into a semantic network (Rada, 1989). One example of such a network is the World Wide Web, which allows users to find information from a vast collection of online documents stored on computers around the world. In education, hypertext systems have proved useful in supporting learning activities like Webquests and blogs, and learning environments like Moodle. Much of the traditional and distance learning has been augmented with information from hyperbooks, online repositories, and web-based encyclopedias like Wikipedia.

Hypertext systems have the same underlying structure. Each hypertext is a network of *nodes* and *links*. Information to be imparted through hypertext appears on the computer screen one unit at a time, in what is referred to as nodes. Nodes are usually brief, self-contained text segments that describe a particular idea. Since the physical space available on the computer screen is limited, text in a node is generally consists of a few concise paragraphs. Thus, a typical hypertext interface allows the reader to select a node, read it, and follow links to other connected nodes.

The *associative trails* that connect hypertext nodes are called links. Links are highlighted, clickable words or phrases embedded in the text that allow users to access information in other conceptually related nodes. Hypertext authors create *relationship potential* of linking by adding a connection to another node, which expands on the existing node of information. Readers, on the other hand, establish the *relationship actuality* of linking by choosing to follow links and examining relationships created between nodes of information (Harrison, 2002). Links are an essential component of hypertext because they allow readers to navigate hypertexts, while also organizing their knowledge representations of connections among the different concepts presented in the text.

Cognitive Processing of Hypertext

Contexts for understanding and organizing complex conceptual information can be provided by both traditional texts and hypertext-based materials. Processing of traditional text and hypertext occurs at many levels. These levels range from low-level reading processes of decoding characters, recognizing words, and parsing sentences to high-level processes of deriving the meaning of the information in the text. In addition to these cognitive processes, reading of both traditional text and hypertext involves metacognitive activities. Readers monitor their comprehension of the text to identify possible information gaps, review information, and allocate attentional resources based on perceived importance of information (Reynolds, 2000).

While understanding of traditional text and hypertext is grounded in the same reading processes, reading hypertext places additional demands on the reader. Reading traditional text usually involves progressing through the information as it is pre-structured and presented by the author. Conversely, in hypertext there is no inherent conceptual flow – the reader is required to use associative links to control the sequence of accessing nodes. After reading each node of information, the reader must select a link to move on to the next node of information to be read. Thus, hypertext readers must actively decide what information to read next, given their interests and learning goals on one hand, and the options provided by the links in the interface on the other. Through this process, readers engage in cognitive monitoring to consider various paths available to them and choose some paths over others (Charney, 1994; Rouet, 1992).

Individual control of information access that is inherent in hypertext-assisted learning is critical in developing advanced knowledge (Spiro, Vispoel, Schmitz, Samarapungavan, & Boerger, 1987). Researchers have hypothesized that user control exercised by readers while selecting information allows them to approach information in the nodes from different intellectual perspectives, and contributes to creation of knowledge that is more flexible and adaptive to various real-life situations (Jacobson & Spiro, 1991). In fact, some scholars have proposed that hypertext is more readily comprehended than traditional text because the flexible, nonlinear structure of nodes and links is designed to mirror the organization of our conceptions of the world (e.g. Jonassen, 1989). According to this perspective, hypertext is a powerful medium to develop cognitively flexible knowledge structures because it requires that readers revisit the same concepts at different times, in re-arranged contexts, for different purposes, and from different conceptual perspectives.

Cognitive Load and Hypertext

Although a number of studies have shown that increased cognitive flexibility and user control tend to enhance transfer of learning (e.g., De La Paz, Swanson, & Graham, 1998; Jacobson & Spiro, 1991; Lawless & Brown, 1997), some researchers suggest that the shift in control of access from author to reader places a greater cognitive burden on the learner and may degrade learning performance (Niederhauser, Reynolds, Salmen, & Skolmoski, 2000; Rouet, Jarmo, Dillon, & Spiro, 1996). The additional processes involved in navigating and making meaning from hypertext require that readers' cognitive system must process more information, creating additional *cognitive load* for the reader.

Cognitive load refers to the mental burden that performing a task imposes on the learner (Sweller, 1988). Three types of cognitive load have been identified. *Intrinsic load* is imposed by the inherent complexity of the content itself. The intrinsic load of information is determined by the extent to which various elements interact. An element is the information that can be processed by a learner as a single unit. Some information can be understood and learned, individual element by individual element because the elements do not interact. Learning the concept of a point is an example of such a low-load task. A point in Euclidean geometry has no size, orientation, or any other feature except position. It has no volume, area or length. Thus, this concept can be learned without reference to any of the other information element. In contrast, high-element interactivity material consists of elements that cannot be understood in isolation because they interact. We can learn certain basic concepts individually but we cannot learn a more complex concept like a circle without considering several concepts and their relations. In this case, higher intrinsic load is caused by the larger number of interacting elements (e.g., point, curve, center, circumference, radius etc.) that must be processed simultaneously.

While intrinsic load is generally thought to be immutable due to the inherent complexity of content (Sweller, 1994), instructional designers can manipulate *germane* and *extraneous* load. Learners experience germane load, when the content or learning activities are designed to encourage cognitive processing and appropriately challenge the learner. For example, an instructional activity that requires students to find a geometric circle in different objects allows learners to reflect on their daily activities, analyze shapes of objects they encounter during these activities, identify circles, and generate an answer. In the context of hypertext-assisted learning, user control that is required of readers to actively decide what links to follow in order to make meaning from hypertext may be regarded as a source of germane load because it engages hypertext readers in deep semantic processing that encourages cognitive flexibility (Niederhauser, Reynolds, Salmen, & Skolmoski, 2000).

The unnecessary load that does not contribute to (or interferes with) comprehension of the to-be-learned content is termed extraneous (Paas, Renkl, & Sweller, 2003). For example, two possible ways to describe the concept of a circle to a young learner may impose different amounts of extraneous load. An instructor can certainly describe a circle verbally, but it takes far less time and mental effort to understand the concept when a learner is shown an image of this geometric shape. In this instance, efficiency of the visual medium is preferred because it reduces extraneous load on the learner. Any reduction in extraneous load frees learner's cognitive capacity for deeper processing of information and permits an increase in germane load. This points to another important characteristic of cognitive load – intrinsic, germane, and extraneous load types are additive in nature; and the sum of different types of load cannot exceed learner's cognitive capacity if learning is to occur (Paas, Tuovinen, Tabbers, & van Gerven, 2003).

Working Memory Limitations

Dynamics of cognitive load is directly influenced by the characteristics of human cognitive architecture (Mayer & Moreno, 2003). Working memory plays a critical role in our cognitive system because it serves as an information-processing buffer between two other memory structures – the highly transient sensory store that registers all incoming sensory stimuli and long-term memory that stores our knowledge representations. Because of this special function, working memory has been equated with consciousness (Sweller, van Merrienboer, & Pass, 1998). Humans are conscious of and can actively process information only in working memory. All other cognitive functioning is disabled unless and until it can be brought into working memory. Thus, learners use working memory as a processing space to mediate the integration of new information and existing knowledge.

Cognitive psychologists have shown that our working memory is limited in capacity and duration. Only about seven meaningful units of information can be stored in it at any given time (Miller, 1956). Furthermore, if information has to be organized, compared, or contrasted only two or three items can be dealt with simultaneously (Sweller, van Merrienboer, & Paas, 1998). Further, the duration of working memory is quite short, with almost all information that has not been integrated into long-term memory being lost within approximately 30 seconds (Peterson & Peterson, 1959). Information-processing demands on working memory have serious implications for hypertext-assisted learning.

The limitations of working memory may create significant challenges for hypertext readers. While in a traditional text the author typically maintains a series of coherent arguments through the text, the defining feature of information presentation in hypertext – linking – requires that the reader be the one who bears the responsibility of comparing and contrasting concepts, and extracting meaning from a network of nodes. In the context of hypertext, it is necessary for readers to analyze and integrate knowledge representations from two or more nodes, if they are to make connections among the concepts presented. The reader must hold representations that involve a concept encountered in the first hypertext node in working memory, while integrating the information in the new node to update his or her knowledge base. The reader then selects another node by following a new link that he or she believes will lead to additional promising information, given the knowledge he or she just integrated from reading the previous nodes. This information integration process continues until the content presented in hypertext is rendered sensible.

Effects of Split Attention

A major problem with processing information in this manner (and the basic foundation for the present work) is the fact that human cognitive architecture does not always allow hypertext readers to optimally integrate concepts from working memory into long-term memory. For example, many of us have probably struggled with reading research papers in which tables that complement the results section are included as appendices at the end of the paper, forcing the reader to flip back and forth between text and tables to make sense of the data. A similar problem can be observed in hypertext-assisted learning. Hypertext readers must make sense of the information encountered in a new node, only if they can relate it to the information integrated from the previous nodes. However, presentation of information in physically separate nodes can make it difficult for learners to interrelate different concepts presented in these nodes. Mental integration in this information-processing situation is compounded by the so-called *split attention*.

The debate on whether it is possible to attend to two sources of information at once has been central to psychology starting as early as 1890s (Benjamin, 1968). Recent empirical research has shown that split attention is caused by intensive search-and-match processes involved in cross-referencing units of information in working memory (Chandler & Sweller, 1992). These additional processes may function as a source of extraneous cognitive load on limited working memory resources, and result in acquisition of knowledge fragments instead of coherent knowledge structures (Kalyuga, Ayers, Chandler, & Sweller, 2003).

Physical integration of related information elements has been proposed to address the problem of split attention and the ensuing extraneous load (Chandler & Sweller, 1991, 1992, 1996; Mayer & Anderson, 1991). Designers of hypertext-assisted learning materials frequently employ navigation aids like menus, guided tours, hierarchies, outlines, and graphical browsers. One characteristic of these learner-support tools, however, is their focus on reducing cognitive load at the global organizational level of hypertext, which provides very little support for comprehension and interrelation of concepts presented in individual hypertext nodes. At the same time, many navigational decisions, and potential situations for split attention, occur when one is selecting a link to a new node. In many cases these embedded, contextual links are the only hypertext navigation method available to the learner.

Leads, which were initially devised by journalists to provide readers with a preview of a newspaper article, may serve as a tool for reducing split attention and helping learners integrate information from different hypertext nodes more efficiently. Leads can function as an *advance organizer* to orient and prepare the reader for information contained in the linked node while the current node is still visible. A lead may occur in the form of a mouse-over balloon that pops up next to the selected link and provides a brief summary of the content that follows in the linked node. Thus, in a lead-augmented hypertext system, the reader has the opportunity to get an idea of what is coming in the next hypertext node without having to leave the current node.

A short summary of the linked node that is contained in the lead functions as a transition between the linked nodes. Leads can serve as a cognitive tool to help hypertext readers reduce the conceptual space between the linked nodes and mentally integrate information. Further, such node previews may assist readers in making user-control decisions to determine an appropriate sequence of accessing and reading the linked nodes. Therefore, leads have the potential to inform hypertext readers' navigation, and function as a metacognitive support tool.

While leads may be innovative in that they have not yet been implemented widely in hypertext for educational purposes, there is evidence that demonstrates the potential value of this cognitive and metacognitive tool. Empirical research has demonstrated the effectiveness of using link comments, which contain a summary of the linked nodes. These link comments have been found useful in hypertext-assisted learning relative to a) improving link selection during a browsing session (Schweiger, 2001), b) integrating textual and pictorial information (Betrancourt & Bisseret, 1998), and c) more recently – enhancing searching and knowledge acquisition (Cress & Knabel, 2003). And, although previous research significantly improved our understanding of the potential role of leads for enhancing learning, it frequently lacked adequate theoretical grounding in human cognition and satisfactory methodological approaches. For example, in the Cress and Knabel (2003) study, no measures of learners' structural knowledge were used to determine the effect of leads – even though the research was grounded in structural and conceptual disorientation.

Research Design

The present research study was designed to assess the effect of leads on extraneous cognitive load, and the resulting learning from conceptually rich instructional hypertext. Unlike the earlier studies discussing link comments, the present study used cognitive load theory as the conceptual framework to ground the work in an adequate theoretical frame. Assessment of the effect of leads was approached from both a learning performance perspective and through measurement of cognitive load. Amount of learners' cognitive load was assessed while they were engaged in a knowledge acquisition task using traditional and lead-augmented hypertext. Subjective and objective methods, including self-reported mental effort, reading rate, and electroencephalogram, were employed. Further, participants' learning performance in the two experimental conditions was assessed and compared based on the measures of recall, as well as conceptual and structural knowledge.

The research design of this empirical study was driven by the following research questions:

1. How does using leads in conceptually rich hypertext affect extraneous cognitive load associated with split attention?

2. To what extent does the use of leads in conceptually rich hypertext affect learning performance?
3. To what extent do individual learner characteristics (e.g., prior knowledge, metacognitive awareness, and reading ability) affect cognitive load and learning in traditional and lead-augmented hypertext?

Literature Review

Learning from hypertext has been central to the debate on the use of technology in education. However, while cognitive flexibility researchers highlight the potential advantages of hypertext as an educational tool, some argue that the defining feature of hypertext – linking – can in fact increase cognitive load and compromise learning. Cognitive processing of hypertext is described in this literature review from both the cognitive flexibility and cognitive load perspective. Discussion of the relevant empirical studies supports the conclusion that linking can increase the chance of split attention and associated extraneous load when processing information from linked nodes. Lead is proposed as a solution to this problem. SUMMARY

The second part of the literature review focuses on the methodological rationale underlying cognitive load assessment. Advantages and limitations of current cognitive load measurement methods are described relative to the task of instructional hypertext processing. This analysis includes a discussion of electroencephalography as a direct measure of cognitive load at the level of neuronal responses in the alpha, beta, and theta brain wave rhythms. The methodological rationale section also includes a review of studies describing research on localization of appropriate electroencephalogram recording sites that reflect working memory processing and cognitive load. Research hypotheses that predict subjects' brain wave behavior in the high-load hypertext condition conclude this chapter.

Theoretical Foundations

Hypertext-assisted learning has been typically described through a wealth of knowledge derived from the field of reading research. For example, several studies demonstrated that measures of recall and reading comprehension used traditional in traditional reading research (e.g., reading rate) could be applied to the study of reading from hypertext (Wenger & Payne, 1996). On the other hand, another body of empirical research literature shows that readers' past experiences and prior knowledge allow them to exercise cognitive flexibility by making choices about the sequence of reading information in hypertext in ways that can't be possible when reading traditional, paper-based text (e.g., Alexander, Kulikowich, & Jetton, 1994).

Cognitive Flexibility Theory

Cognitive flexibility is a concept that has driven the development of hypertext-assisted learning. Cognitive flexibility theory originated in the 1980s, when first hypertext systems were developed to accommodate for the need to store and manage vast amounts of information (Spiro, Vispoel, Schmitz, Samarapungavan, & Boerger, 1987). That was a time when the dominant model of learning was schema theory, - a cognitivist approach that emphasized the role of mental representations (*schemas*) stored in the long-term memory. Cognitive psychologists arrived at the concept of schema from studies of memory in which subjects recalled details of stories that were not actually there (Bransford & Franks, 1971). This line of research suggested that knowledge is stored in our memory in the form of schemas, which provide a mental framework for understanding and remembering information (Bartlett 1932, 1958; Mandler, 1984; Rumelhart, 1980). These schemas facilitate making inferences about instances of the concepts they represent. For example, if one knows that something is a house, one can use the schema definition to infer that it is made of wood or brick, it has rooms, walls, windows, and doors, and that its function is to provide lodging (Anderson, 1995).

One problem with schema theory that some cognitivists noted was that one could not have a pre-stored schema for everything that one might encounter (Spiro & Myers, 1984). This explained the notorious difficulty in achieving “transfer,” that is reconfiguration of prior knowledge and its application to new situations that differ from the initial conditions and contexts of learning. Cognitive flexibility theory was developed as a successor to schema theory to address this problem. Its primary goal was to replace the notion of rigidly prepackaged schemas with more open and adaptable ones – knowledge that would be applicable across the wide range of real-life situations in which it might be required (Spiro, Collins, Thota, & Feltovich, 2003).

To produce such open and widely applicable knowledge structures, it became clear that learning could not proceed in a single direction, organized into neat categories. Instead, cognitive flexibility theory described and explained the active nature of learner engagement in the process of “criss-crossing the conceptual landscape”, a metaphor created by Wittgenstein in 1953 (Spiro, Vispoel, Schmitz, Samarapungavan, & Boerger, 1987). This theory proposed that in learning one explores a knowledge domain by going from one case to the next following different routes of organization on successive traversals of the knowledge landscape. Sometimes, one returns to the same case but coming from a different set of perspectives. Each case appears to be unique and multifaceted, requiring the learner to consider a variety of dimensions at once (Spiro, Collins, Thota, & Feltovich, 2003).

Cognitive flexibility theorists soon realized that the best way to approach this kind of ill-structured and multifaceted learning is by highlighting random access capabilities of computers (Spiro, Coulson, Feltovich, & Anderson, 1988), the kind of nonlinear methodology they referred to as “Random Access Instruction” (Spiro & Jehng, 1990). As a result, this group of researchers began an effort to design cognitive flexibility hypertext systems, based on the principles of cognitive flexibility theory, and applicable to such diverse domains as teacher preparation, medicine, military strategy, history, and so forth.

For cognitive flexibility researchers, hypertext is more than a presentation medium; it is also a useful vehicle for testing their theoretical model. In this perspective, a major practical advantage of hypertext is its potential of being explored in different ways, with the different exploration paths producing what are essentially multiple texts for the same topic (Spiro & Jehng, 1990). The linked organization of hypertext allows the learner to access nodes from different paths, and thus introduces opportunities for learners to integrate new knowledge into their existing conceptions, and relate concepts in ways that are not likely to take place as a result of traditional, sequential presentations of information (Cunningham, Duffy, & Knuth, 1993; Jonassen, 1988, 1991; Jonassen & Wang, 1993). With the help of this medium, information can be compared and contrasted, synthesized and analyzed according to the learner's prior knowledge in the subject matter.

Role of Prior Knowledge

The amount and quality of reader's prior knowledge is one of the factors that impact integration of information from flexible hypertexts into the reader's knowledge base. Readers' background knowledge allows new information to be incorporated into their existing schemas. Experimental evidence demonstrates that readers who do not have an adequate amount of prior knowledge on the subject of a text will have a lower comprehension of the text (Spilich, Vesonder, Chiesi, & Voss, 1979). This study showed that background knowledge enabled readers to provide coherence to the text, permitting better bridging inferences between noncoherent text sections. A more recent study showed how subject matter contributed to readers developing a unique self-guided text when reading hypertext (Alexander, Kulikowich, & Jetton 1994). That is, readers' past experiences and prior knowledge led them to make choices about the sequence of reading information in the hypertext in ways that are not possible when reading traditional text.

Due to the flexibility of hypertexts, readers with little background knowledge may have additional difficulties when compared with low-knowledge readers of equivalent traditional texts (Foltz, 1996). High-knowledge readers already have pre-stored schemas for the knowledge domain, Hypertext structure may therefore be very familiar to them. A reader with little prior knowledge of the subject matter, however, is unlikely to recognize the structure of hypertext. Thus, a low-knowledge reader may not be able to accurately choose the relevant hypertext nodes when creating their path through the learning material. This problem may not be as evident in traditional texts, because they typically provide a single path to access the information. Low-knowledge readers are expected to follow this path, even if they have trouble comprehending the text.

Role of Metacognition and User Control

Cognitive activity related to integrating new knowledge into prior knowledge schemas requires that learners must know how to direct and actively monitor their cognitive processes (Shapiro & Niederhauser, 2004). Thus, a key aspect of the cognitive flexibility theory appears to be the ability of the learner to regulate their learning or *metacognition* (Baker & Brown, 1984; Flavell, 1979, 1987; Garner, 1987). Metacognition refers to higher-order thinking, which involves active control over the cognitive processes engaged in learning. Accordingly, metacognitive strategies are processes that one uses to control cognitive activities, and to ensure that a cognitive goal (e.g., understanding a text) has been met. These processes help regulate and oversee learning, and consist of planning and monitoring cognitive activities, as well as evaluating the outcomes of those activities.

Empirical evidence demonstrates that increased metacognition is represented by better developed metacognitive strategies and tends to enhance learning (De La Paz, Swanson, & Graham, 1998; Derry & Murphy, 1986; Nist, Simpson, & Olejnik, 1991; Reynolds, 1992). Active learning through reading, for example, involves internally exercising metacognition to allocate attentional resources based on perceived importance of information and effectiveness of comprehension strategies (Reynolds, 2000). In the context of hypertext-assisted learning, increased metacognition has been shown to be beneficial to learning (e.g., Shapiro, 1998). This particular experiment demonstrated that learners who were forced to be metacognitive when navigating a relatively ill-structured hypertext system performed better on a post-test of conceptual knowledge than their counterparts who didn't have to exercise much metacognition when learning from a more well-structured system.

Metacognition is closely connected with user control – the process of translating cognitive activity into operating the program to select information to be viewed. Hypertext systems are frequently described as flexible and interactive particularly because they require that users control access to information by navigating through multiple text nodes. Increased user control has been shown to improve information recall and retention (e.g., Lawless & Brown, 1997).

User control issues are frequently centered around the question of whether the learner or the system should control access to information (e.g. Milheim & Azbell, 1988; Patterson, 2000; Shin, Schallert, & Savenye, 1994). One experiment, for example, examined the effects of user control versus program control on high-school students using a hypertext-based learning program (Kinzie, Sullivan, & Berdel, 1988). Subjects in the user control condition exhibited better results on the tests of conceptual knowledge than those in the program control condition.

Conversely, another body of research literature demonstrates that a greater degree of user control in instructional systems like hypertext and multimedia may in fact prove detrimental by placing greater cognitive demands on the learner (e.g., Paas, Renkl, Sweller, 2003). When learning from hypertext, readers must monitor to a greater extent whether they understand what has been read, determine whether information must be sought to close information gaps, and decide where to look for that information in the hypertext. These processes require that learners' cognitive system must now process more information, and thus work under a certain level of stress.

The negative effects of increased user control and metacognition have been demonstrated in a study aimed at determining the effectiveness of a hypertext system that was designed according to the principles of cognitive flexibility theory (Niederhauser, D. S., Reynolds, R. E., Salmen, D. J., & Skolmoski, 2000). These researchers hypothesized that students who took advantage of the compare and contrast links within a large hierarchical hypertext on learning theories would gain a deeper understanding of this complex domain than those who chose not to use these linking features. The compare and contrast link feature was designed purposely to provide alternate paths to information. The hypothesis was based on the premise that learning would be enhanced due to a) the deep semantic processing required to compare and contrast information, b) increased metacognition associated with monitoring and guiding the learning process, and c) provision of user control to make navigational decisions.

Unexpectedly, results of this experiment indicated that learners who used links to compare and contrast concepts tended to have lower scores on the tests of learning than those who employed a more sequential reading approach characteristic of reading traditional text. The latter group chose not to make conscious decisions about navigating the hypertext. They adopted a strategy for reading hypertext that minimized their use of cognitive resources associated with constructing an individualized path through the text. On other hand, students who made extensive use of the compare and contrast linking capabilities in the hypertext tended to be less successful. Use of cognitive resources to make navigational decisions and the resulting user control may have inhibited students' ability to integrate new knowledge into existing knowledge structures. The benefits these students could have gained from engaging in deeper processing by comparing and contrasting the content may have been confounded by the increased *cognitive load* associated with navigating the hypertext.

Cognitive Load Theory

Cognitive load is defined as the mental burden that performing a task imposes on the cognitive system (Sweller, 1988). It is generally accepted that performance degrades at the cognitive load extremes of either excessively low load (underload) or excessively high load (overload). Under conditions of both underload and overload, learning may be compromised (Paas, Renkl, & Sweller, 2004; Teigen, 1994). So, whereas learning contexts with low processing demands may benefit from instructional conditions that challenge the learner and increase the load, situations with an extremely high cognitive load benefit from a reduction of load to manageable levels (Wulf & Shea, 2002).

Cognitive load theory suggests that learning happens best under conditions that are aligned with human cognitive architecture (Paas, Renkl, & Sweller, 2004). From this perspective, architecture of the human mind consists of three major components: sensory store, short-term (working) memory, and long-term memory.

Human Cognitive Architecture

Sensory store registers and stores sensory stimuli that humans need to maintain awareness of the surroundings. These are sights, sounds, smells, tastes and touches. A separate partition of sensory memory exists for each of the senses. This structure is highly transient – it retains the sensory image for only a small fraction of a second, just long enough to develop a perception.

Working memory is the part of our cognitive architecture, which receives stimuli from the sensory store, and in which active information processing is held. Current models describe working memory as mechanisms and processes that control, regulate, and actively maintain task-relevant information (Miyake & Shah, 1999). For example, the well-known Baddeley model of working memory assumes the existence of a central executive that coordinates two subordinate systems, a visuospatial sketchpad for visuospatial information such as written texts or pictures and a phonological loop for phonological information such as spoken text or music (Baddeley, 1986; Baddeley & Logie, 1999). Both these subordinate systems are assumed to be limited in capacity and independent from each other in that the processing capacities of one system cannot compensate for lack of capacity in the other. The capacity of working memory is has been shown to be very limited. Only about seven elements can be stored in working memory at any given time (Miller, 1956). The exact number of items has been shown to depend upon a number of factors such as age, level of fatigue, expertise in the content area, complexity of information, and priming (e.g., Baddeley, 1994; Baddeley, Thomson, & Buchanan, 1975; Stoltzfus, Hasher & Zacks, 1996). Further, if information has to be organized, compared, or contrasted only two or three items can be dealt with simultaneously (Sweller, van Merrienboer, & Paas, 1998). Finally, almost all information stored in working memory and not updated or rehearsed into long-term memory is lost within approximately 30 seconds (Peterson & Peterson, 1959).

In contrast to working memory, long-term memory is assumed to have a virtually unlimited capacity and duration. Long-term memory stores information processed by working memory and deemed relevant by the central executive. This information is housed in prior knowledge schemas that categorize information elements according to the context in which they were (and will be) used and vary in their degree of automation (Chi, Glaser, & Rees, 1982; Paas, Renkl, & Sweller, 2004). Similar to cognitive flexibility theory, cognitive load theory stipulates that expertise develops through the construction of increasing numbers of ever more complex and adaptable knowledge representations by integrating elements of lower-level schemas into higher-level schemas.

The processes of schema construction and automation can free the capacity of working memory. Knowledge organized in schemas allows learners to categorize numerous interacting elements of information into a single unit, thus reducing cognitive processing in working memory. With extensive practice, schemas become automated, thereby allowing learners to further bypass capacity limitations of working memory. From an instructional design perspective, it follows that design of learning materials should encourage both construction and automation of schemas (Paas, Renkl, & Sweller, 2004). Hence, cognitive load theory is concerned with techniques for managing working memory resources in order to facilitate the changes in long-term memory associated with schema construction and automation.

Cognitive Load Types

Cognitive load is defined as the total amount of mental activity imposed on working memory at an instance of time (Sweller, 1988). It is additive in nature and consists of intrinsic, extraneous, and germane load. The load is called intrinsic when it is imposed by the number of information elements and interactivity between them, which are inherent in the content itself. If it the load is imposed by the manner in which the information is presented to learners and by the learning activities required of learners, it is called either extraneous or germane. Whereas extraneous (or ineffective) cognitive load is imposed by presentation formats and activities that do not contribute to the processes of schema construction and automation, germane (or effective) load enhances presentation of information and learning activities that foster these processes. Thus, a high cognitive load can be the result of a high intrinsic cognitive load (i.e., the result of the nature of instructional content itself). It can, however, also be the result of a high extraneous or germane cognitive load as a consequence of the design and presentation of the learning materials. In other words, the same learning material can induce different amounts of cognitive load when different designs and strategies are used for its presentation, because the different cognitive tasks required by these strategies and designs are likely to result in varying amounts and patterns of extraneous and germane load. When the difference between the total cognitive load and the processing capacity of the visual or auditory channel of working memory approaches zero, the learner experiences an overload. The amount of this difference, on the other hand, comprises free cognitive resources (Brunken, Plass & Leutner, 2003).

Split Attention

A possible source of extraneous cognitive load in hypertext-assisted learning is the feature that differentiates hypertext from traditional text – linking. Links are used to connect different nodes in a hypertext system and enable learners to explore hypertext in different ways, facilitating development of flexible and adaptable schemas (Jonassen, 1993; Spiro & Jehng, 1990). While in a traditional text the author typically maintains a series of coherent arguments through the text, the linking feature of hypertext requires that the reader be the one who bears the responsibility of comparing and contrasting concepts, and extracting meaning from a network of nodes. It is necessary for readers to analyze and integrate knowledge representations from two or more nodes, if they are to make connections among the concepts presented in hypertext. The reader must hold representations that involve a concept encountered in the first node in working memory, while integrating the information in the new node to update his or her knowledge base. The reader then selects another node by following a new link that he or she believes will lead to additional promising information, given the knowledge he or she just integrated from reading the previous nodes. This information integration process continues until the content presented in hypertext is rendered sensible. Therefore, in the context of hypertext, instructional material can only be understood after the learner has mentally integrated information from two or more nodes.

A major problem with processing information in this manner (and the basic foundation for the present work) is the fact that human cognitive architecture does not always allow hypertext readers to optimally integrate concepts from working memory into long-term memory. A number of empirical studies have shown that when different sources of information are separated in space (e.g., hypertext nodes), the learner's attention is split between these sources, and thus the essential learning processes of schema construction and automation are compounded with intensive search-and-match procedures, which are involved in cross-referencing elements of various schemas. This type of cognitive processing may frequently place an unnecessary strain on limited working memory resources (Kalyuga, Ayers, Chandler, & Sweller, 2003). An example from every day life that demonstrates the effect of split attention might be a situation in which a person drives a car and talks on a cellular phone at the same time. Additional cognitive processing caused by mental integration of the consequences of these two activities results in a high level of extraneous cognitive load; therefore talking on a cellular phone has been prohibited while driving a car in many countries, especially in the case of teenager drivers whose cognitive system cannot endure the multitasking and excessive amounts of cognitive load that many adults are used to.

A similar problem can be observed in hypertext-assisted learning. Hypertext readers must make sense of the information encountered in a new node, only if they can relate it to the information integrated from the previous nodes. However, presentation of information in physically separate nodes can make it difficult for learners to interrelate different concepts presented in these nodes. Mental integration in this information-processing situation is compounded by the so-called *split attention*.

The split attention effect has been described in the cognitive load literature primarily in the context of learning with multimedia. For example, empirical evidence has shown that when an image or diagram is placed far from the piece of text that it complements, the required search-and-match information integration processes result in additional cognitive demands and inhibit learning (Kalyuga, Chandler, & Sweller, 1999; Sweller, Chandler, Tierney, & Cooper, 1990; Tarmizi & Sweller, 1988). Similarly, another study has explained that split attention occurs even when reading conventional text such as experimental papers because the results section and the discussion section in these texts are reported separately, yet need to be considered simultaneously to understand the complex of results and their implications (Chandler & Sweller, 1992). Thus, one might conclude that split attention and the resulting high levels of extraneous cognitive load can occur in any situation that requires simultaneous consideration of two or more sources of information or activities.

External integration of related information elements has been proposed as a solution to reducing extraneous load associated with split attention (Chandler & Sweller, 1991, 1992, 1996; Mayer & Anderson, 1991, 1992). For example, in an attempt to solve the split attention problem caused by physically separate text and diagram, these information sources have been integrated by directly embedding sections of text onto the diagram in close proximity to corresponding components of the diagram, and presented simultaneously with the diagram. Such integration of related elements of diagrams and texts reduced visual search and mental integration, thus decreasing the extraneous load on working memory (Chandler & Sweller, 1996).

Leads as a Tool to Reduce Split Attention in Hypertext

One obvious solution to the problem of reducing split attention and the ensuing extraneous load in the context of hypertext-assisted learning appears to be complete elimination of links and physical integration of all hypertext nodes into one undivided unit. While this conversion of flexible, random-access hypertext to traditional, sequential text presented on a computer seems to solve the problem of split attention, efforts to reduce high extraneous load by using linear, “linkless” formats may reduce germane cognitive load. The cognitive processes of comparison and elaboration that facilitate construction and automation of flexible, adaptive schemas in the cognitive flexibility view may be disrupted by such presentation formats. Thus, such conversion would seem to defeat the purpose of hypertext, – that is provision of flexible information structures, both from the perspective of cognitive flexibility theory, and from the point of view of cognitive load theory.

Various solutions have been developed to address the problem of split attention and extraneous load in hypertext. A recent development in hypertext design, for example, deals with adapting hypertext to the abilities, needs, interests, and goals of a particular user. Adaptive hypertext systems provide tools that scaffold and personalize content via adaptive presentation and/or navigation based on a user model that stores information about user expertise, goals, and interests. Not surprisingly, the most common feature adapted in hypertext systems is the links (Shapiro & Niederhauser, 2004). Links can be enabled or disabled for given users, or they may be annotated. Typical types of annotations will tell users whether a document has already been viewed or if they have sufficient experience or knowledge to view a document's content. Unfortunately, whereas such technological innovations are under vigorous pursuit by engineers and computer scientists, very few empirical studies on the educational effectiveness of these technologies have been reported. The majority of studies that do address learning are plagued by methodological problems (Shapiro & Niederhauser, 2004). In addition, recent results suggest that while learners seem to appreciate the scaffolding tools and personalization offered by adaptive hypertext systems, learners overall would prefer to have greater control over the system's functionality (Papanikolaou, Grigoriadou, Kornilakis, & Magoulas, 2003).

Another set of mechanisms that have been developed to address the problem of split attention are tools used primarily in static, non-adaptive hypertext systems. Static hypertexts frequently employ contextual navigation aids such as various types of menus, views, guided tours, hierarchies, and graphical browsers. Comprehension aids like objectives, glossaries, summaries, and outlines are used to facilitate mental integration of information on the part of the learner and reduce extraneous cognitive load.

One characteristic of many of the above learner-support tools, however, is their focus on reducing cognitive load at the global organizational level of hypertext (e.g., menus, site maps, and hierarchies), which provides very little support for comprehension and interrelation of concepts presented in individual hypertext nodes. At the same time, many navigational decisions, and potential situations for split attention, occur when one is selecting a link to a new node. In many cases these embedded, contextual links are the only hypertext navigation method available to the learner.

Few tools have been developed to reduce the mental space between linked nodes in hypertext systems. Research on the educational use of *advance organizers* (Ausubel, 1960) provides evidence that these tools can support text comprehension and learning. Advance organizers are short texts that contain the central concepts of a larger text, which follows in a more abstract and general way (Cress & Knabel, 2003). These brief texts are designed to activate relevant schemas, which are already established in the learner's long-term memory, thus enabling the learner to integrate new information more efficiently and effectively. Effectiveness of advance organizers has been shown to depend on text coherence, – they were most effective in supporting learning in an unstructured text condition (Mayer, 1978).

Leads, which were initially devised by journalists to provide readers with a preview of a newspaper article, may serve as a tool for reducing split attention and helping learners integrate information from different hypertext nodes. Numerous books have been written to highlight the utility of different types of leads in various writing endeavors (e.g., Rosenauer, 2004). The most common types of leads discussed in the literature are summary leads, example leads, and quote leads. In the context of hypertext, summary leads can function as an advance organizer to orient and prepare the reader for information contained in the linked node while the current node is still visible. A lead may occur in the form of a mouse-over balloon that pops up next to the selected link and provides a brief summary of the content that follows in the linked node. Physical integration of information presented in different hypertext nodes that is provided by leads may prove valuable in helping learners overcome the split attention effect and mentally connect the concepts presented in linked nodes in a hypertext-based learning system. Thus, in a lead-augmented hypertext system, the reader has the opportunity to get an idea of what is coming in the next hypertext node without having to leave the current node.

A short summary of the linked node that is contained in the lead functions as a transition between the linked nodes. Leads can serve as a cognitive tool to help hypertext readers reduce the conceptual space between the linked nodes and mentally integrate information. Further, such node previews may assist readers in making user-control decisions to determine an appropriate sequence of accessing and reading the linked nodes. Therefore, leads have the potential to inform hypertext readers' navigation, and function as a metacognitive support tool.

While leads are innovative in that they have not yet been implemented widely in instructional hypertext, there is empirical evidence that demonstrates the potential value of this cognitive and metacognitive tool. For example, one study explored the effectiveness of link comments (*Linkgestaltung*), which popped up next to the mouse (Schweiger, 2001). These comments contained a summary of one or two sentences of the content of the linked page. Results showed that these comments improved intentional link selection and reduced incidental link selection (serendipity) while browsing. In a related research study, Betrancourt & Bisseret (1998) provided empirical evidence that popup windows enhanced searching while they did not disturb learning. The popup window that they used contained word definitions and other additional information about linked text elements. In contrast to the comments used in the first study (i.e., Schweiger, 2001), these popups had to be actively requested by the user – application of the user control principle of cognitive flexibility theory. Another study investigated the effect of a functionally similar tool – page preview – in two conditions: searching and knowledge acquisition (Cress & Knabel, 2003). Fifty participants were instructed to explore a hypertext with the aim of either understanding as much as they could or searching for information. Results of this study demonstrated that page previews enhanced knowledge acquisition in both conditions and supported intentional and incidental learning. In the searching condition previews were used for link selection, even if they could not enhance the search results.

In a more recent study, the effect of mouse-over hyperlink previews was investigated from the point of view of human-computer interaction (Maes, van Geel, & Cozijn, 2006). In this usability experiment three groups of participants were exposed to three different versions of a website: a) without hyperlink previews, b) with content oriented, semantic previews, and

c) with task-oriented, pragmatic previews. A semantic preview summarized information from the linked node, and a pragmatic preview related node information to task execution. Participants were asked to execute search and knowledge acquisition tasks, and to evaluate task and hypertext. The results showed an overall advantage for previews in terms of task efficiency, but no effects on effectiveness or appreciation. The authors concluded that previews fit with the step-by-step goal orientation of hypertext users. Once the users were acquainted with the use of this tool, pragmatic previews sped up their decision making.

Although prior research significantly improved our understanding of the potential role of leads for enhancing learning, it frequently lacked adequate theoretical grounding in human cognition and satisfactory methodological approaches. For example, in the Cress and Knabel (2003) study, no measures of learners' structural knowledge were used to determine the effect of leads – even though the research was grounded in structural and conceptual disorientation.

Methodological Rationale

Measurement of Cognitive Load

Cognitive load has been defined as a theoretical construct that describes mental processes of information processing that cannot be observed directly. Therefore, measurement of cognitive load has been driven by indirect methods that allow researchers to *infer* the amount of cognitive load expended on a learning task. These methods typically do not allow to obtain load estimates which are fairly time-specific, which show load fluctuations on the levels of instantaneous, peak, average, and accumulated load, and which allow to identify the different types of cognitive load such as extraneous load associated with ineffective presentation of the materials and germane load that enhances learning.

Traditionally, prediction of cognitive load has been carried out on the basis of the learning material's intrinsic difficulty and the user's level of prior knowledge with respect to the subject matter. But since such predictions can't be entirely precise and reliable, more direct ways of assessing cognitive load have been proposed over the years (for an overview see Paas, Tuovinen, Tabbers, & van Gerven, 2003). Although there exist many methods of cognitive load assessment, each one of them can be assigned to one of four classes: 1) analytic measures, 2) subjective measures, 3) behavioral measures, and 4) psychophysiological measures (Schultheis & Jameson, 2004). When applied to the context of hypertext-assisted learning, each of these methods may have its advantages and disadvantages.

Analytic Measures

Cognitive load estimation can be based on general (i.e., not interaction-specific) information about the system and the learner. For example, analysis of the intrinsic difficulty of a hypertext and the expertise of the user reading this hypertext can form a basis for the prediction of the user's cognitive load. This method of cognitive load assessment can produce invalid results because it relies heavily on prior knowledge, and does not take into account information about the current interaction, system design, and individual learner characteristics such as metacognitive awareness.

Subjective Measures

The intensity of effort expended by learners has been shown to be a reliable measure of cognitive load (e.g., Paas & van Merriënboer, 1993, 1994a). Subjective techniques of assessing cognitive load are based on the assumption that people are able to introspect on their cognitive processes and report the amount of mental effort expended. Although self-reports may appear questionable (e.g., Feldon, 2005), it has been demonstrated that people are quite capable of giving a fairly accurate numerical indication of their perceived cognitive load (Gopher & Braune, 1984). Subjective measures of cognitive load usually involve a questionnaire comprising one or multiple semantic differential scales on which the participant can indicate the experienced level of mental effort. Most subjective measures are multidimensional in that they assess groups of associated variables, such as mental effort, fatigue, and frustration, which are highly correlated (for an overview, see Nygren, 1991). Studies have shown, however, that reliable measures can also be obtained with unidimensional scales (e.g., Paas & van Merriënboer, 1994b). Such scales have been shown to be sensitive to relatively small differences in cognitive load, and that they are valid, reliable, and unintrusive (e.g., Gimino, 2002; Paas, van Merriënboer, & Adam, 1994).

Behavioral Measures

With the third group of methods, cognitive load is inferred from the learner's overt behavior. Evidence of this type might be, for instance, the amount of time, which the learner spends on reading hypertext. Obviously, this technique does not reflect the variations in cognitive load, and it is appropriate only if the activity yields a sufficiently high rate of observable behavior. These disadvantages can be avoided through the introduction of a secondary task. For example, a hypertext reader may be asked to attend to auditory stimuli and push a button when a certain pattern of sounds occurs. Poor performance on the secondary task in this case would indicate that the primary task of reading induces a high cognitive load. Although this approach partially avoids the above-mentioned disadvantages, introduction of a secondary task itself may be problematic, because it disturbs the learner's primary activity.

Psychophysiological Measures

Finally, changes in various bodily processes and states have been observed to covary with changes in cognitive load. Therefore, monitoring of these bodily functions may allow load to be inferred. A major advantage of many psychophysiological measures is the continuous availability of bodily data, which potentially allows load to be measured with a high rate and high degree of sensitivity. Moreover, without the introduction of an extra task, information about cognitive load is available even in situations in which overt behavior is relatively rare. Consequently, as compared with the other classes of methods, psychophysiological measurement seems to be especially promising for dynamic assessment of cognitive load in a task that involves reading.

Unfortunately, with many of the existing psychophysiological measures online assessment in an applied context is cumbersome. Most of them require electrodes to be attached to the body (e.g., electroencephalography, galvanic skin resistance) or the use of equipment that entirely rules out deployment in everyday situations (e.g., functional magnetic resonance imaging, positron emission tomography, magnetoencephalography). Others, again, seem to be too indirectly linked to cognitive load (e.g., blink rate, blink duration, heart rate variability), or to be too slow for online measurement (e.g., hormone level). Recent experiments on the use of task-evoked pupillary responses as a cognitive load measure in human-computer interaction (Iqbal, Zheng, & Bailey, 2004) and assessing cognitive load for adaptive hypermedia (Schultheis & Jameson, 2004) demonstrate that even pupil size – a measure that has none of the disadvantages described above – is not a suitable measure of cognitive load for tasks that involve continuous reading.

Brain Activity Measures: Event-Related Potentials and Electroencephalogram

Some researchers have suggested that cognitive load can be measured directly and objectively with brain activity measures (Brunken, Plass, & Leutner, 2003). Analysis of the historical development of research on human brain activity reveals that at least two measures of brain activity can be used as measures of cognitive load – event-related potentials and electroencephalogram (Basar, 2004).

In the late 1970s and early 1980s brain signals recorded with electroencephalography (EEG) were widely considered to be simple idling of the brain. Research based on event-related potentials (ERPs) appeared to be more promising than on EEG, which was regarded as background noise to be rejected from the recordings. Unlike the EEG, which represents spontaneous brain activity, ERPs are generated as a response to specific stimuli, and are an average of a number of samples. These ERPs are time-locked to stimulus events and have proven valuable to psychophysiologists, even in situations where no other noticeable response occurs.

With regard to cognitive load measurement, one particular ERP, the P300, has been given special attention. This potential is elicited when a low-probability task-relevant stimulus is encountered (i.e., a stimulus to which the subject is attending). The procedure that utilizes this property of the P300 in cognitive load assessment has been to introduce a secondary task containing stimuli that elicit the P300. Magnitude of the evoked P300 gives information about the cognitive load in the main task: the larger the amplitude, the smaller the load. Unfortunately, with this method the subject is required to perform a secondary task, which may disturb the primary activity. To minimize effects of the secondary task, a new technique has been proposed by Schultheis and Jameson (2004), which relies on the Novelty-

P300 (Friedman, Cycowicz, & Gaeta, 2001). This special subtype of the P300 is elicited by highly unexpected, previously unexperienced (i.e., novel) stimuli even if these stimuli are not attended to. As a result, the evoking stimuli do not have to be embedded in a secondary task. Instead, the Novelty-P300 can be elicited by a sequence of stimuli which are (a) presented simultaneously with the task of the user but (b) not relevant to that task. Regarding cognitive load, the Novelty-P300 has the same properties as the original P300: the Novelty-P300 is smaller for higher cognitive load (Ullsperger, Freude, Erdmann, 2001).

While the ERP methodology clearly has its advantages relative to cognitive load assessment, the pessimistic perspective towards EEG as a measure of cognitive activity has been deemed unwarranted in the face of new theoretical and methodological developments (e.g., Basar, 2004). These scientific advancements suggest a renaissance in the application and value of the EEG methodology. Numerous studies have been conducted investigating spontaneous brain dynamics and the role of brain oscillations in determining various attentional and cognitive functions (e.g., Gruzelier, 1996; Ota, Toyoshima, & Yamauchi, 1996; Pfurtscheller, Neuper, & Mohl, 1994). These studies jumpstarted new and exciting developments in the analysis of the EEG activity.

EEG activity is a measure of the amplitude and frequency of electrical activity taking place below a particular location on the skull. It is measured typically at the surface of the scalp and is amplified and recorded. Whereas recording tools like functional magnetic resonance imaging capture a “snapshot” of the brain activity, EEG is useful for tracking changes in brain activity over a period of time, identifying patterns of electrical activity in the cortex, and noting responses to stimuli in fractions of a second. Thus, a major advantage of using EEG in the context of cognitive load assessment is that it may allow identification of structural types of cognitive load such as instantaneous load, peak load, average load, and accumulated load (e.g., Xie & Salvendy, 2000). In the context of the present study, EEG recordings may prove useful because they represent a detailed trend and pattern of the mental activity of the learner at different stages of exploring an instructional system such as hypertext (e.g., navigating menus, reading headings, and following hyperlinks to linked texts).

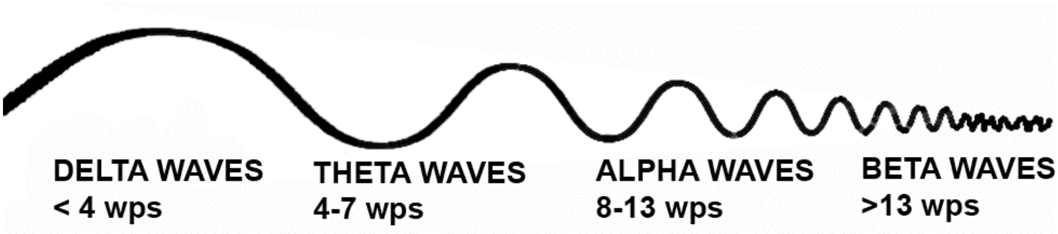
Neural Oscillations and Cognitive Activity

Drawing from the renewed interest of the neurophysiological research community in the EEG, Basar (1999) established a brain theory based on neural oscillations. He traced the development of this theory over several decades from analyzing the firing of individual neurons, functional groups of neurons and the brain as an integrated whole, and showed the functional significance of the brain's electrical activities. In particular, he outlined how EEG can be used to detect brain wave rhythms and how these rhythms can be considered a type of "alphabet for brain functions" (Basar, 1980). He proposed that wavelike potential changes serve as direct and measurable indices of specific brain activities. According to this theory, brain oscillations can be correlated with multiple functions that include sensory registration and tracking, perception, movement, and cognitive processes related to attention, learning and memory (Basar, 1999).

A critical evaluation of this hypothesis requires an understanding of the nature of brain wave rhythms. At present, it is believed that electrical activity in the brain generates at least four distinct rhythms (Basar, 1999). Figure 1 shows that brain waves are a continuum from the large, slow delta and theta waves to faster (i.e., higher frequency) alpha and beta waves.

Figure 1

Human brain wave frequencies (waves per second)



Alpha

Alpha is the predominant brain wave rhythm. It is frequently used as a baseline when wakeful subjects are asked to close their eyes. When the eyes are opened, a suppression (or desynchronization) of alpha activity occurs indicating alert attention (Appendix A). Alpha rhythm is recordable from at least 85 percent of humans in the 8-13 waves per second range (referred to as Hertz or Hz) and have an amplitude ranging from 20 to 200 microvolts (μV) (Fisch, 1999). Different areas of the brain are more likely to generate a particular waveform, and the alpha rhythm is most prominent in the occipital and parietal lobes (Lubar, 1991; Rothschild, Thorson, Reeves, Hirsch, & Goldstein, 1986). Researchers have repeatedly observed that alpha rhythm is related negatively to many types of cognitive activity (e.g., Greenfield & Sternbach, 1972). As cognitive activity increases, the alpha rhythm tends to desynchronize and the overall amplitude has a tendency to decrease below the 20 μV range (Fisch, 1999; Geske, 2005). Because of the well-documented inverse relationship between alpha and cognitive activity, alpha frequency is the most often studied and reported dependent measure when examining various types of mental activity, tasks, and stimuli (Basar, 2004; Rothschild, Thorson, Reeves, Hirsch, & Goldstein, 1986).

Beta

Beta rhythm varies between 14 and 30 Hz and is associated primarily with the normal conscious state and active processing of information. Beta waves are prominent mostly in the central and frontal areas, and characterized by a much smaller amplitude ranging from 2 to 20 μV. Some observers believe that beta varies positively with attention (Geske, 2005) or that beta is the result of alpha suppression (Greenfield & Sternbach, 1979). A general agreement among neurologists is that higher beta frequency indicates more intense cognitive processing (Basar, 1999). There are also data to show that beta varies with alpha (Gevins et al., 1979), which has led some researchers to speculate that beta may in fact be a spillover from, or harmonic of, alpha (Doyle, Ornstein, & Galin, 1974). The upper beta range (above 30 Hz) is frequently referred to as gamma (Fisch, 1999).

Theta

Theta rhythm is the most intensively investigated phenomenon in neurophysiological studies aiming at correlating rhythms with cognitive functions (Basar, 1999). There is evidence that the midline prefrontal region of the cortex can generate theta activity in certain cognitive states. For example in one study, EEG rhythms of 5 to 5.5 Hz appeared with some regularity during the performance of simple repetitive mental-arithmetic tasks (Mizuki et al, 1980). Spectral analysis of frontal EEGs showed that theta rhythm was faster during motor or verbal learning tasks (Lang, Lang, Diekmann, & Komhuber,1987). The discussion of Miller's corticohyppocampal interplay theory (1991) also concludes that theta activity in frontal regions is associated with a theta activity in the hippocampus.

Delta rhythm (0.5 Hz - 3 Hz) indicates sleep patterns and a loss of consciousness. Delta waves are present in waking states, but an increase in delta activity generally reflects a move toward drowsiness and sleep and away from attention and active processing of information (Geske, 2005).

Measurement of the changes in brain wave rhythms reflects what is happening in the subject's information processing situation, even if the subject is unaware of the changes or is not unable to verbalize what is happening during the processing (Basar, 1999). Therefore, EEG-based measures of cognitive activity may appear promising relative to the measurement of cognitive load. A number of studies have attempted to connect responses in brain wave rhythms to the assessment of cognitive load. For example, one study demonstrated that there is an inverse relationship between alpha power and task difficulty (Gale & Christie, 1987) – as the task difficulty increases alpha power tended to decrease. Another study analyzed EEG data obtained from 15 Air Force pilots during air refueling and landing exercises performed in an advanced technology aircraft simulator (Sterman, Mann, Kaiser, s& Suyenobu, 1994). These researchers found a progressive suppression of 8-12 Hz activity (alpha rhythm) with increasing amounts of cognitive load. A similar result demonstrated an inverted-U relation between alpha activity and behavioral arousal, using a reaction-time task to increase arousal and using rest to lower arousal (Ota, Toyoshima, & Yamauchi, 1996). It is remarkable that the relation was not found with alpha amplitude or frequency but with a rate of change measure, - the difference between rest and task divided by the sum of the two values. An abrupt decrease in beta power and blocking of alpha during higher levels of attention were found in an earlier experiment (Horst, 1987).

Similar decreases in theta activity as task difficulty increased and during transitions from single to multiple tasks were revealed independently by Natani and Gomer (1981), and Sirevaag and colleagues (1988). A somewhat contradictory finding was reported in a more recent study that showed that short-term memory demands lead to synchronization in the theta band manifested in an *increase* in band power; at the same time, long-term memory demands lead to a task-specific desynchronization in the upper alpha band, manifested in a *decrease* of power (Klimesch, 1996).

Event-Related Desynchronization as a Measure of Cognitive Load

A measure for wave desynchronization that has advanced the models of both Basar and Klimesch is termed *event-related desynchronization* and is defined as the percentage of decrease or increase in band power during a test interval with respect to a reference interval (Pfurtscheller & Aranibar, 1977; Pfurstscheller & Lopes de Silva, 1999). Any time period, following the reference interval can be used as test interval. Thus, with a series of test intervals, the time course of shifts in band power can be monitored over the entire trial. The percentage of increase or decrease in band power is calculated for each electrode and experimental condition according to the formula presented in Figure 2 (Pfurstscheller & Lopes de Silva, 1999). A positive ERD% value indicates a decrease in band power with respect to the reference interval whereas a negative value indicates an increase in band power. Therefore, positive values reflect a state of event-related desynchronization, negative values – a state of event-related synchronization.

Figure 2

Computation of event-related desynchronization percentage

$$ERD\% = \frac{\text{baseline interval band power - test interval band power}}{\text{baseline interval band power}} * 100$$

Application of the event-related desynchronization method has led Klimesch (1996) to conclude that those cortical areas which are involved in the processing of a task tend to desynchronize (and reflect a decrease in power), whereas other areas which most likely are not primarily involved either tend to synchronize or show little power changes. Further findings revealed that complex tasks show (a) a significant higher level of desynchronization (b) a longer lasting duration of desynchronization and (c) a more widespread topographical distribution of desynchronization than less complex tasks (Klimesch, 1999). These basic results were obtained not only for motor tasks with varying complexity (e.g., Pfurtscheller & Berghold, 1989) but also for memory tasks (Klimesch, Schimke, & Schwaiger, 1994; Klimesch, Doppelmayr, Russegger, & Pachinger, 1996). The fact that both alpha frequency and memory performance tend to decline with age together with the findings of earlier experiments exploring alpha rhythm and cognitive activity allowed Klimesch to hypothesize that the alpha band reflects memory processes (1994).

To test this hypothesis, Klimesch and colleagues (1994) designed a study which recorded the power of alpha and theta bands, and in which they were able to distinguish long-term memory (LTM) from short-term memory (STM) retrieval processes. The experimental design used an *n-back* task (i.e., one that requires to continuously keep a string of *n* items in mind) and consisted of two parts. Subjects first performed a semantic congruency task in which they had to judge whether or not the sequentially presented words of concept-feature pairs (such as 'eagle-claws' or 'pea-huge') are semantically congruent (LTM). Then, without prior warning, they were asked to perform an episodic recognition task (STM). This was done in an attempt to prevent subjects from using LTM encoding strategies and thus to increase STM demands. In the STM task, the same concept-feature pairs were presented together with new distractors (generated by re-pairing known concept-feature pairs). Now subjects had to judge whether or not a particular concept-feature pair was already presented during the LTM task. Results of this experiment indicated that despite the fact that the LTM task was easier than the STM task, the upper alpha band showed a significantly stronger desynchronization during the processing of the feature in the LTM task. Further, the theta rhythm also appeared to be an important oscillatory indicator of LTM and STM processes, - while LTM demands led to a task-specific desynchronization in the upper alpha band (*decrease* of power), STM demands actually led to event-related synchronization in the theta band manifested in an *increase* of band power.

Effects of Working Memory Processes and Tasks on Brain Activity

In another study designed to test the influence of memory load on theta and alpha, Klimesch (1999) used another task – a modified *Sternberg memory scanning task*, the varied/consistent mapping paradigm. Memory load was manipulated by two factors, set size (5 or 10 characters, number and letters) and mapping condition. Under the consistent mapping condition, subjects knew, which characters the memory set of the next trial will contain, and under the varied condition, each memory set contained different characters (numbers and letters). In the varied condition memory load was particularly high because subjects had to avoid confusing the current memory set with the preceding one. The results of this experiment showed that unlike their previous study (Klimesch, 1996) upper alpha behaved quite similar to theta in the most difficult (varied, set size 10) as compared to the easiest condition (consistent, set size 5). Both frequency bands show a significant memory load dependent *increase* in band power during the *encoding and retention* interval (i.e., the interval between the presentation of the memory set and retrieval). Despite these similarities in load dependent changes, only upper alpha showed a pronounced desynchronization during *retrieval*, whereas theta exhibited a load-dependent synchronization. The same result was also obtained in a more recent study (Jensen & Tesche, 2002).

Considering these consistent findings of a load-dependent increase in upper alpha power in a Sternberg task during encoding and retention, the question arises why, in n-back tasks, an *increase* in frontal theta but a *decrease* in alpha was found. According to Klimesch (2005), the answer most likely has to do with differences in memory tasks, analyzing techniques, and, most importantly, with the finding that in contrast to encoding and retention alpha desynchronizes during retrieval. The n-back task is a continuous memory task that characterizes reading: subjects have to keep the previous item in mind (active maintenance), encode the currently presented item, and perform task-specific scanning and retrieval (executive control). In other words, different types of memory processes must be carried out continuously and in parallel. Because it is quite demanding, the n-back task elicits an *increase* in frontal midline theta power (as shown by Fingelkurts, Fingelkurts, Krause, & Sams, 2002; Jensen & Tesche, 2002; Klimesch, Doppelmayr, Schwaiger, Auinger, & Winkler, 1999; McEvoy, Pellouchoud, Smith, & Gevins, 2001; Raghavachari et al., 2001) and because different processes must be carried out (almost) in parallel, alpha synchronization during retention counteracts with alpha desynchronization during retrieval (Klimesch, 2005). This latter effect will have a particularly strong impact if periods of one second or longer are used for calculating power spectra (which actually was the case in most studies using the n-back task).

One study that is particularly relevant to the present investigation used the n-back paradigm to assess short-term memory load during computer use by eight participants performing high-, moderate-, and low-load short-term memory n-back tasks (Gevins et al., 1998). Subjects performed two versions of the task at each of three levels of difficulty. In a verbal version, participants were required to remember the identity of the visual stimulus presented; in a spatial version, they were instructed to remember its position on the screen. In the low-load (LL) difficulty level, participants were required to compare the current stimulus with a stimulus presented on the previous trial. If the current stimulus matched the one presented on the previous trial, they were asked to respond by pressing a microswitch. In the verbal version, a "match" was a stimulus that was the same letter as the one presented on the previous trial (regardless of its position on the screen); in the spatial version, a match was a stimulus that was in the same position as in the previous trial (regardless of what the letter was). A "nonmatch" decision was indicated by a right middle finger response. In the moderate-load (ML) difficulty level, participants were required to compare the current stimulus with the one presented two trials ago. In the high-load (HL) difficulty level, participants were required to compare the current stimulus with the one presented three trials ago. Match stimuli occurred randomly on 50 % of the trials. Given that trials were four and a half seconds long, participants were required to remember the identity or location of each stimulus as well as its sequential order for nine seconds in the ML level and for thirteen and a half seconds in the HL level. Visual inspection of average power spectra collapsed across participants revealed topographically distributed task-related EEG modulation in multiple frequency bands. In agreement with the previous findings (Klimesch, 1996, 1999), theta activity was largest at the frontal lobe. A Task Version x Load Level ANOVA on theta power at this location revealed a significant level effect, that is theta *increased* with increasing task difficulty. Alpha was largest over parietal and occipital regions. A Task x Load x Site ANOVA revealed a significant level effect, with alpha *decreasing* from the lowest to the highest working memory load level. Beta activity at the midline central site (Cz) significantly *decreased* as load increased. Gamma was largest at lateral frontal, temporal, and occipital locations. There were no statistically significant differences in gamma power across the group, but some individual participants displayed consistent increases in this band with increasing load.

Localization of Cognitive Load Recording Sites

A major consideration for the measurement of cognitive load with EEG is localization of appropriate recording sites on the subjects' cortex. EEG recording sites have been standardized through the use of the 10-10, or 10-20 system proposed by the International Federation of Societies for Electroencephalography and Clinical Neuropsychology (Jasper, 1958). EEG patterns recorded from widely spaced scalp electrodes are quite diverse. This variability is due to the structural and functional differences between brain sites underlying the electrodes. Therefore, correct interpretation of EEG recordings depends upon accurate localization of recording sites.

In the context of the present study, EEG recording sites have to meet two main criteria. First, it is important to attach EEG electrodes to those areas of the skull that have been shown to be superior at conducting brain waves of certain rhythms. For example, the best site for collection of alpha waves appears to be the posterior parietal region, while beta and theta rhythms are most prominent in the frontal lobe of the cortex (Basar, 1999; Gevins, et al, 1998; Klimesch 1996, 2005). Second, EEG recording sites must reflect the cognitive activity under investigation. Evidence from neurological research based on functional magnetic resonance imaging (fMRI) provides important insights as to what areas of the human cortex are responsible for reflecting cognitive load sensitive processes.

As described above, the construct of cognitive load is grounded in the assumption of the limited capacity of working memory. Working memory is responsible for the short-term storage and online manipulation of information necessary for higher cognitive functions including learning (Baddeley, 1986; Shallice, 1988). Based on this theory, two types of processes have been singled out in the working memory: executive control (governing the encoding manipulation and retrieval of information in working memory) and active maintenance (keeping information available online). It has also been proposed that these two types of processes may be subserved by distinct cortical structures, with the prefrontal cortex housing the executive control processes and more posterior regions housing content-specific buffers (i.e., phonological versus visuospatial) that are responsible for active maintenance (Gathercole, 1994; Paulesu, et al, 1993).

Using the temporal resolution of fMRI, Cohen and colleagues (1997) examined the dynamics of regional activation associated with a sequential-letter working memory task in human subjects. They showed that both prefrontal cortex and parietal cortex appear to play a role in executive control and active maintenance. Specifically, activity in the areas involved in working memory *varied as a function of memory load*, with greater activation at higher levels of load. Furthermore, such load-sensitive areas dissociated into two types: those involved in active maintenance exhibited sustained activation throughout the trial, whereas those involved in other memory functions (assumed to be time-limited, such as updating working memory contents, decision processes and so on) exhibited transient activation but peaked higher at higher levels of load. Thus, these areas showed an interaction between the effects of time and load (Cohen, et al, 1997).

More recent neurological research aimed at identifying the capacity limit of visual short-term memory with fMRI has produced another interesting finding (Todd & Marois, 2004). Even though visual short-term memory is known to be supported by an extensive network of brain regions (e.g., Basar, 2004; Callicott, et al., 1999; Goldman-Rakic, 1996; Zhang & Linden, 2003), its capacity limit appears to be neutrally reflected only in *one* node of this network – the posterior parietal cortex. When asked to remember visual or verbal symbols, the left posterior parietal cortex of right-handed subjects was consistently activated. As the subject was required to retain the symbols for longer periods of time, *Broca's area* (lateral frontal cortex) became progressively more active (which might indicate rehearsal). As the authors explain, Broca's area may be a buffer, or temporary circuit that mirrors signals back to the posterior parietal region, in the absence of further sensory input. Other studies also showed that as Broca's area becomes more active, so does the parietal region, supporting the notion of a feedback loop (e.g., Cohen, et al., 1997; Jonides, et al, 1998).

The posterior parietal area as well as (pre)frontal cortex, therefore, appear to be two important structures of the human brain that are useful in terms of collecting information about cognitive load that is induced by the limited capacity of working memory's visuospatial sketchpad (which is responsible for processing visual information such as written texts or images). These conclusions are in accord with the well-known *Brodmann map of the human brain* (Appendix B), which demonstrates that the parietal area of the cortex reflects processing of visual information (left hemisphere for right-handed subjects), while the frontal cortex houses cognitive processes. These findings also echo with the results of EEG research on cognitive load reported above (e.g., Basar, 1999; Gale, 1987; Gevins et al., 1998; Horst, 1987; Klimesch, 1996).

Cognitive Load Measurement Hypotheses

The above-described studies corroborate Basar's theory (1999) that brain wave rhythms can be used to assess brain activity, and that even-related desynchronization percentage can serve as a measure of cognitive load. Potentially, use of the EEG methodology may allow for a more accurate assessment of mental activity in a given information processing situation than self-reports, as it can also measure pre-conscious processing associated with the presentation of information (e.g., bottom-up and top-down attention, as described in Geske, 2005).

Based on the findings of research studies aiming to correlate alpha, beta, and theta power changes with memory processes and cognitive load (Cohen, et al., 1997; Gevins et al, 1998; Klimesch, 1996, 1999, 2006; Todd & Marois, 2004), it may be proposed that increased cognitive load is reflected by the following oscillatory indicators:

- A *decrease* in alpha power as evidenced by *larger positive ERD%* value in the posterior parietal cortex
- A *decrease* in beta power as evidenced by *larger positive ERD%* value in the frontal cortex
- An *increase* in theta ERD% as evidenced by *larger negative ERD%* value in the frontal cortex

Summary

The above literature review demonstrated that cognitive load theory serve as a theoretical framework for the analysis of hypertext-assisted learning. The limitations of human working memory may complicate the cognitive processing of hypertext, particularly due to split attention when learners integrate concepts presented in separate hypertext nodes.

Physical integration of concepts may be achieved through leads, which provide a short summary of the content in the linked nodes, and may potentially decrease extraneous cognitive load associated with negative effects of split attention. Literature also indicates that psychophysiological cognitive load measures like event-related desynchronization percentage of alpha, beta, and theta brain waves can serve as a direct measure of this theoretical construct.

Methodology

The purpose of this experiment was to determine whether leads (independent variable) affect (a) learners' cognitive load and (b) learning performance (dependent variables), while subjects navigated and read conceptually rich hypertext. Subjective, behavioral, and psychophysiological methods served as measures of cognitive load, while conceptual and structural knowledge tests, as well as a recall measure were used to determine learning performance. Subjects' reading ability, level of prior knowledge in the domain, and metacognitive awareness were used to determine the effect of individual differences on cognitive load and learning from traditional and lead-augmented hypertext.

Subjects

Subject Identification

The subject pool consisted of 22 education majors enrolled in the teacher education program of a large Midwestern university. An initiation to participate was e-mailed to all undergraduate education majors (N=687). Fifteen dollars and a chance to win an iPod Nano were used as an incentive. The 22 students who responded most promptly were enrolled as subjects in the study.

Literature suggests that gender, handedness, age (Giannitrapani, 1988), and race (Sandhu, Fong, & Rigney, 1996) can differentially affect brain waves. In addition, some studies show that women tend to underestimate their performance in self-report measures (Merrill, Seeman, Kasl, & Berkman, 1997). This variance issue is typically addressed through either subject selection, or via extensive post hoc statistical analyses. In this study subject selection was used as the method to control for variance associated with subjects' interpersonal differences. The subject pool was limited to white, right-handed females, and only young adults ages 18 to 23 were invited to participate in this experiment. As brain wave patterns can be affected by brain disorders, students with these conditions, or those taking medications to treat these conditions, were not eligible to participate as subjects. All subjects were pre-tested for reading ability, and were asked to wear appropriate corrective lenses if needed. Two subjects were removed from the pool for the following reasons. One subject was fatigued after having had a midterm examination, and fatigue has been shown to affect brain waves (Perry & Childers, 1969). The second subject exhibited abnormal alpha wave patterns (her alpha amplitude was smaller in the relaxed mode than in the active-reading, cognitive-load mode), - a phenomenon that is rare but not uncommon (Orne & Wilson, 1978).

Demographics

The remaining 20 subjects were native speakers of English and experienced computer and hypertext users. Half of the subjects were raised in a family with low to medium income, while the other half came from more affluent families. The sample consisted of 10 seniors, 3 juniors, 2 sophomores, and 5 freshmen. Most of the subjects were majoring in Elementary Education (n=11), five of them were students in Early Childhood Education, two in Mathematics, one in Biology, and one in Family and Consumer Sciences. Subjects described themselves as novices in the content area of educational psychology, even though 13 of them reported having taken an educational psychology course. Seven subjects preferred reading websites to reading books. Most subjects reported taking courses which required them to read text from websites at least once per week (n=11). Seven subjects reported reading course information from websites occasionally, and two students always printed all web-based materials before reading them.

Materials

Materials for the study included four texts on learning theories, a hypertext presentation system, and measures to assess reading ability, metacognitive awareness, prior knowledge, cognitive load and learning performance.

Learning Theory Texts

Four conceptually rich instructional texts were developed to address the foundations of one of four major learning theories: Behaviorism, Information Processing, Cognitive Constructivism, and Social Constructivism. Texts were created using the following resources: (a) Theory Into Practice (TIP) database (Kearsley, 2007), and (b) WikEd (Hursh, 2004). Both of these resources granted permission to use, modify, and distribute their content under the Creative Commons license.

Hypertext structure was consistent with what is referred to as “schema driven design” (Lawless & Brown, 1997; Niederhauser, et al., 2000). Each text included of a primary passage and seven linked nodes. These primary passages were optimized to contain 500 ± 5 words. Each of these passages contained seven links to subordinate nodes describing the theory’s social context, influential theorist, view of knowledge, and four major principles or concepts. Nodes contained 90 ±5 words. All texts were measured and corrected to have equivalent Flesch reading difficulty score of 35. Text difficulty and content validity were established independently by four experts in educational psychology.

Information Processing and Cognitive Constructivism texts were augmented with summary leads. Texts on Social Constructivism and Behaviorism did not contain leads. Leads were designed to include 10 ± 2 words.

Hypertext Presentation System

The hypertext presentation system was designed using guidelines suggested by state-of-the-art web usability research (Nielsen, 2006). It was developed to be viewed as a single frame with a minimum screen resolution of 800 by 600 pixels. Georgia sans-serif font was used to present all text with black lettering on a white background with no tracing images or watermarks. Font size was set to 100 percent. Three styles were used to identify links to subordinate nodes: (a) blue, underlined for all new, non-active links; (b) purple, underlined for all visited, non-active links; and (c) red, underlined for active links (Krug, 2000).

Each hypertext node consisted of a banner indicating the name of the learning theory, and instructional text in the body of the frame. Four criteria were used in designing the hypertext system to avoid contamination of the research with system variables other than those of interest in the present study. (1) No images were used to remove variance associated with media other than text. (2) Only contextual (embedded) linking was available as a navigation method to remove variance associated with different navigation options (e.g., menus, maps, lists etc.) (3) No links to external websites were included to control access to information. (4) All new nodes opened in the same browser window, so subjects could only view one information frame at a time.

The variable of interest in this study was the use of leads. Leads were presented as mouse-over popup balloons, which introduced the content presented in each of the seven subordinate nodes in the given passage. Balloon background color was set to a non-transparent yellow to provide sufficient contrast with the white background of the frame, while not being excessively dark for the black lettering used in the leads. The font size of the text within the leads was reduced to 80 percent to contrast lead text with text presented in the primary passage. All popup balloons were 300 pixels wide, which made up about 27 percent of the total width of the frame. Presentation of the leads was based on a mouse-over event (rather than mouse-click). Subjects were able to roll the cursor over the link, read the lead, and then decide whether to click on the link and proceed to the subordinate node. Lead balloons covered the remainder of the current line of text and part of the two lines of text underneath the link to ensure that subjects attended to the lead after it was activated (rather than continuing to read the text that followed the lead-augmented link). A screenshot of the lead-augmented hypertext system is presented in Appendix C.

Measures

Pre-Test Measures

Subjects were required to complete the following pre-test measures: (a) a 52-item Metacognitive Awareness Inventory (Schraw & Dennison, 1994); (b) a 12-item prior knowledge test, (c) a 24-item reading comprehension test (Brown, Bennett, & Hanna, 1981); and d) a brief demographic information questionnaire.

Metacognitive Awareness

In the present study subjects' metacognitive awareness was measured using the Metacognitive Awareness Inventory (Schraw & Dennison, 1994). In this instrument items are classified into two metacognitive factors – knowledge of cognition and regulation of cognition. All items were written using a 5-point Likert scale. In a study analyzing use of comprehension aids in a hypermedia environment with college students as population, Cronbach's α for the MAI was estimated at .86 indicating adequate internal consistency (Bendixen & Hartley, 2003).

Prior Knowledge

A domain knowledge pre-test was used to determine subjects' prior knowledge. This multiple-choice test consisted of three questions on each of the four learning theories covered in the text. Four-alternative answers were presented for each question.

Reading Ability

Reading comprehension was assessed using the Nelson-Denny advanced reading comprehension test, Form E (Brown, Bennett, & Hanna, 1981). This test contained four texts on various topics and a series of multiple-choice questions for each passage for a total of twenty four questions. Subjects had 25 minutes to complete the test.

Demographics Questionnaire

All subjects filled out a demographics questionnaire that consisted of 17 items. The subjects were asked to report their major, year in school, and whether they had taken any classes in educational psychology. The subjects also provided information on their experience and confidence in using computers, the Internet, and their preference for reading texts from books or websites.

Cognitive Load Measures

Cognitive load is as a theoretical construct describing the internal information processing that cannot be observed directly. However, to use this concept to inform the design of instruction, valid and reliable instruments assessing cognitive load are needed. The various methods of assessing cognitive load that are currently available have been classified along two dimensions: (a) objectivity – subjective or objective, and (b) causal relation – direct or indirect (Brunken, Paas, & Leutner, 2003). The objectivity dimension describes whether the method uses subjective, self-reported data or objective observations of behavior, physiological conditions, or performance. The causal relation dimension classifies methods based on the type of relation of the phenomenon observed by the measure and the actual attribute of interest. For this experiment we utilized three cognitive load measures that represent both these dimensions (Table 1).

Table 1

Cognitive Load Measures Used in Experiment

	Direct	Indirect
Objective	Electroencephalogram	Reading time
Subjective		Self-reported mental effort

Electroencephalogram

The direct, objective method of measuring subjects' cognitive load used in this experiment was the electroencephalogram (EEG). EEG data were acquired with a BIOPAC MP30 unit connected to a Macintosh G4 MiniMac computer. Electrode placement was confined to one set of electrodes over the prefrontal cortex (F7) and one – over the parietal lobe (P3) in the left hemisphere of the right-handed female subjects. EEG data were collected for all four hypertexts at a sampling rate of 500Hz. Electrode placement followed the Modified Combinatorial Nomenclature, expanded 10-20 system as proposed by the American Clinical Neurophysiology Society (Jasper, 1958; Appendix D). The EEG software presented brain wave rhythms as separate channels allowing to identification of the following wave components: (a) raw EEG signal, (b) alpha rhythm, (c) beta rhythm, and (d) theta rhythm.

Self-Reported Mental Effort

The second measure of cognitive load used was an indirect, subjective method. This technique is based on the assumption that subjects can accurately report their perceived amount of mental effort on a one-item nine-alternative symmetrical category scale, by which subjects report their perception of cognitive load as a numerical value. The rating scale used in this experiment to determine subjects' cognitive load was a version of the Bratfisch, Borg, and Dornic (1972) scale for measuring perceived task difficulty as modified by Paas (1992). Numerical values and labels assigned to the categories ranged from *very, very low mental effort* (1) to *very, very high mental effort* (9). Reliability of the scale with a population of college students was estimated with Cronbach's coefficient alpha at .90 (Paas & van Merrienboer, 1994(a)). The scale was provided and discussed with the subjects before testing began.

Reading Time

Higher cognitive load in the context of a reading task can also be reflected by larger reading times (Just & Carpenter, 1993). In this experiment subjects were instructed to read each hypertext at their natural pace until they felt that they have understood it. Reading time was recorded for each node as well as for the entire hypertext system and served as an indirect, objective measure of the subjects' cognitive load.

Measures of Learning

Recall Task

Upon completing the reading of the four hypertext systems on learning theories, all subjects were asked to recall everything they could about each of the four learning theories presented in the hypertexts. The experimenter showed each subject a visual prompt containing the name of the learning theory the subject covered first, and recorded her oral report on this learning theory into an audio file. This procedure was repeated, with subjects recalling information about each learning theory in the order they were presented to subjects during the experiment. Recall was measured by counting individual concepts that subjects mentioned during the oral report on each theory. Subjects received one point for each correctly recalled concept.

Structural Knowledge Measure

Subjects' structural knowledge was determined using the Inspiration™ concept mapping program. Each subject was presented with a template containing four names of learning theories and related concepts, which were presented randomly on the screen (Appendix E). Subjects were instructed to arrange the 28 concepts presented in the subordinate hypertext nodes under each of the four learning theories. Subjects received one point for each correctly placed concept, yielding the maximum score of 28 points.

Conceptual Knowledge Test

Finally, subjects' conceptual knowledge was assessed using a multiple-choice test (Appendix F). Subjects were to answer forty four-alternative, randomly presented questions that addressed the content covered in both the primary passage and each of the seven subordinate nodes. For example, subjects were asked:

How do behaviorists believe we learn?

a. Associations between stimuli and responses become automatic
b. Through fear of punishment
c. By making sense of experiences
d. From trial and error

Setting

The pretest session was conducted in a spacious, adequately lit university classroom equipped with a set of desks, chairs, and a whiteboard. The subjects were sitting one person at a desk, with a pencil and pretest materials arranged in front of them on the desk in the order, in which they were to be completed.

The experimental phase took place in a physiological testing laboratory approximately 12 feet by 16 feet. All walls were painted white. The ceiling was a white drop-panel design with recessed fluorescent lights. Each set of fixtures contained three bulbs on separate switches. Luminescence in the room was measured at subjects' eye level and at a distance of approximately 50 centimeters from the screen using a Tenma Digital Lux meter (558 ± 15 lux). For control of illumination, no external light was allowed to enter the room. The testing room was in a quiet area removed from hallways or distracting audio stimuli. The room had a separate heavy door to further guard against sound.

Subjects sat in an adjustable-height chair with a high back and armrests facing a blank white wall with white walls on both sides in peripheral vision. On the table in front of the subject at a distance of about 50 centimeters was a 17-inch LCD monitor for displaying the experimental hypertext. The monitor was set to the highest available resolution of 1280 by 854 pixels and maximum level of brightness. A Tenma Digital Lux meter was employed to check the luminosity of hypertext as displayed on the computer screen (107 ± 5 lux). Measurements indicated that luminosity was equal for all texts.

Procedure

Before the experimental phase all subjects attended a pre-test session to complete pre-test measures. Each subject scheduled to attend the experimental phase during the two weeks following the pre-test. At the beginning of the experimental session, the subject was greeted and given instructions on the procedure of the experiment. The experimenter attached disposable vinyl electrodes (Ag/AgCl) to two recording sites on the subject's skull: a) pre-frontal lobe (F7) to collect data on the power of beta and theta waves, and b) parietal lobe (P3) to collect data on the power of alpha waves. Measurements took place referenced to the left mastoid with the earlobe serving as ground and electrode impedance below 10 k. The EEG signal was passed through an Infinite Impulse Response (IIR) bandpass filter to remove any unintended artifacts of movement, and retain only the frequency components that were of interest in the present study. The present study focused on collecting brain waves of the following frequencies: theta (4-7 Hz), alpha (8-13 Hz), and beta (14-30 Hz). Two more sets of electrodes were attached to collect the subject's electrooculogram and electromyogram of the lead hand (to be used in filtering out artifacts associated with eye movement, blinking, hand movement and mouse clicking).

After all electrodes were placed and the EEG equipment was activated, the subject was seated comfortably in front of a computer screen with her eyes closed in a relaxed mode until an extended alpha pattern was noted, and the individual's baseline measure of brain waves was recorded. The subject was then asked to open her eyes (blocking of the alpha rhythm occurred), and read and navigate the first hypertext system presented on the LCD screen. The subject was instructed to minimize all movement during the reading and browsing task. Upon finishing reading each experimental text, the subject completed a mental effort scale, then closed her eyes and returned to the baseline condition (extended alpha). The researcher opened a second experimental text, while the subject was entering the relaxed mode. After 30 seconds, the subject was instructed to open her eyes and browse and read the second text, and then complete a mental effort scale. This procedure was repeated for the remaining two texts. The sequence of presenting texts to subjects was counterbalanced: “lead/no lead/lead/no lead” or “no lead/lead/no lead/lead.”

Navigation path and reading time (in seconds) were recorded for each experimental text via screen capture. Each time the subject clicked on a link in the two traditional hypertexts or opened a lead in the two lead-augmented hypertexts, a marker was placed on the EEG recording. After the subject finished reading the fourth hypertext system, she was instructed to close her eyes to return to an alpha state, which provided an end point for the recording of brain waves.

For the post-test phase, the subject completed four word jumbles as an interpolated task to clear her working memory. The subject’s learning performance was assessed in the following sequence: recall task, structural knowledge test, and conceptual knowledge test. Finally, oral debriefing was conducted to determine subjects’ perceptions as to whether they found leads to be helpful or distracting. The sequence of all activities in the pre-test, experimental, and post-test phases of this study is outlined in Table 2.

Table 2

Sequence of Activities

Pre-Test	1. Prior knowledge test (10 min.) 2. Metacognitive awareness inventory (15 min.) 3. Reading comprehension test (30 min.) 4. Demographic questionnaire (5 min.)

Experimental Phase	1. Eyes closed, extended alpha pattern (30 sec.) 2. Hypertext 1 (10-15 min.) 3. Self-report on mental effort 4. Eyes closed, extended alpha pattern (30 sec.) 5. Hypertext 2 (10-15 min.) 6. Self-report on mental effort 7. Eyes closed, extended alpha pattern (30 sec.) 8. Hypertext 3 (10-15 min.) 9. Self-report on mental effort 10. Eyes closed, extended alpha pattern (30 sec.) 11. Hypertext 4 (10-15 min.) 12. Self-report on mental effort 13. Eyes closed, alpha (30 sec.)
Post-Test	1. Interpolated task – word jumbles (3 min.) 2. Recall test (15 min.) 3. Structural knowledge test (10 min.) 4. Conceptual knowledge test (30 min.) 5. Oral debriefing (5 min.)

A possible disadvantage of the procedure described above can be carryover effects from one treatment to the next. To circumvent this problem, subjects were asked to close their eyes and relax before and after reading each text, and only after they returned to a resting alpha baseline state, were they instructed to proceed to the next treatment. A second concern cited is that subjects can determine the purpose of the experiment and alter their behavior based on their perceptions of what the researcher wants them to do (e.g., the Hawthorne effect). In the present study, all subjects knew the nature of the experiment in advance, and while subjects can learn to alter their brain waves, it typically takes at least 30 sessions of biofeedback training to affect a change in brain wave patterns (Shouse & Lubar, 1979). Thus, for the average subject, the dependent variable of brain wave reactions was automatic and beyond any control of the subject.

A major limitation of using the EEG method for the task of hypertext reading is the necessity to conduct extensive post-acquisition transformation of the data to remove eye movement, blinking, hand movement, and mouse-clicking artifacts. Therefore, besides the EEG, an electrooculogram and an electromyogram was recorded for each subject, and then mapped over the EEG channels to eliminate the above-mentioned artifacts.

Computation of Event-Related Desynchronization Percentage

Based on research findings reported in the literature review, it was to be expected that when subjects moved from a relaxed, eyes-closed state (the control state for this experiment) to an eyes-open, active reading state, higher cognitive load would be associated with higher brain wave *desynchronization* for alpha and beta rhythms, and higher brain wave *synchronization* for the theta rhythm. Consequently, Event-Related Desynchronization percent (ERD%), which compares brain wave power in the test condition with the brain wave power in the baseline condition (Figure 2), would be a positive number for the subjects' alpha and beta rhythms and reflect wave desynchronization, and a negative number for the theta rhythm, which reflects wave synchronization. Increased cognitive load would be associated with larger desynchronization percent values for alpha and beta waves on one hand, and larger synchronization percent values for theta waves on the other.

Figure 2

Computation of event-related desynchronization percentage

$$ERD\% = \frac{\text{baseline interval band power - test interval band power}}{\text{baseline interval band power}} * 100$$

Band power values of the subject's alpha, beta, and theta brain waves in the experimental and baseline conditions are required to compute ERD% and infer the amount of subject's cognitive load. These values were estimated with the software that is preloaded on the BioPac psychophysiometrical system. One function – Area – was employed to calculate the power of each subject's brain waves. This function computes the total area under the curve among the waveform and the straight line that is drawn between the endpoints. Thus, this measure takes into account both wave frequency (Hz) and wave amplitude (μV).

The Area function was used to compute the power of alpha, beta, and theta brain waves over a 20-second time period of subjects' accessing every traditional and lead-augmented link in the experimental texts and the 20-second time period of subjects' brain wave power in the relaxed (baseline) condition. First, area computations were performed for the 20 seconds of the baseline condition obtained from every subject before she started reading each of the four texts. These computations resulted in four values, which were entered as baseline interval band power for each text in the ERD% formula. Then area was computed for the 10 seconds spent by the subject before selecting each of the seven traditional or lead-augmented links, and 10 seconds spent after clicking on the link and reading text in each of the seven subordinate nodes. The reason for separating area computation for the experimental texts into two 10-second time periods lies in the fact that in the lead-augmented hypertext condition subjects accessed the lead and processed information contained in it *before* they clicked on the link to open the subordinate node. Values of the area computed for the 10 seconds before and 10 seconds after clicking on the link were added to yield a total value of the area for the 20 seconds of test interval band power for every link or lead within each of the four texts.

Using the values of baseline interval band power and test interval band power that were obtained via the Area function, ERD% was computed for every subject, for each of the three brain wave rhythms, each of the four texts, and each of the seven links or leads within a text. Thus, for each text used in this study, seven ERD% values were estimated for the subject's alpha rhythm, seven values for the beta rhythm, and seven values for the theta rhythm. Several cycles of averaging had to be performed to reach an integrative grand average ERD% value for every subject's brain wave rhythm in each of the two experimental conditions. First, the seven ERD% values for the alpha rhythm were averaged for each subject yielding one alpha ERD% value for each text. Then, the two alpha ERD% values were averaged for the two traditional texts, and the two alpha ERD% values were averaged for the two lead-augmented texts. As a result, the researchers obtained a single integrative grand average alpha ERD% value for each of the two experimental conditions. The same set of averaging procedures was conducted for every subject's beta and theta rhythm yielding a single grand average beta ERD% value and a single grand average theta ERD% value for each experimental condition. Absolute values were used in reporting theta ERD% because unlike alpha and beta ERD%, an increase in theta power and therefore a negative ERD% for the theta rhythm was assumed to reflect increased cognitive load. Grand average ERD%

values for alpha, beta, and theta rhythms were entered into subject reports and used in statistical analyses.

ERD% results that were obtained by comparing alpha, beta and theta power in the baseline and experimental condition, were reviewed on a case-by-case basis to see if the data indicate a directional movement toward or away from cognitive load. Table 3 presents a sample subject report that reflects alpha, beta, and theta power and ERD% obtained from the pre-frontal (F7) and parietal (P3) cortex, in the baseline condition, traditional hypertext condition, and lead-augmented hypertext. While many studies stop at this descriptive interpretation, this study also tested for statistically significant differences in mean cognitive load and learning performance between the two experimental conditions.

Table 3

Sample subject report

	Lead-Augmented Hypertext			Traditional Hypertext		
	Alpha P3	Beta F7	Theta F7	Alpha P3	Beta F7	Theta F7
Baseline power	23.14	16.21	22.98	21.27	17.79	19.47
Text 1 power	14.83	11.79	25.72	11.87	12.01	22.85
ERD%	35.91	27.27	(-)11.92	44.19	32.49	(-)17.36
Baseline power	25.87	18.09	29.83	27.71	20.83	31.54
Text 2 power	16.24	13.26	33.64	14.86	13.34	36.85

ERD%	37.22	26.70	(-)12.77	46.37	35.96	(-)16.84
Mean ERD%	36.57	26.99	(-)12.35	45.28	34.23	(-)17.1

Results

In accordance with these research questions, the findings are presented in three sections: a) analysis of cognitive load data, b) analysis of learning performance data, and 3) effects of learners' individual differences on cognitive load and learning.

Analysis of Cognitive Load Data

The first research question of this study focuses on determining the effect of leads on extraneous cognitive load associated with split attention. A 5 X 2 repeated measures MANCOVA was conducted to determine the effect of leads on learners' cognitive load. Five measures of cognitive load were used as dependent variables: a) reading time; b) self-reported mental effort; and Event-Related Desynchronization percentages of c) the alpha brain wave rhythm; d) the beta rhythm, and e) the theta rhythm. Presence of leads (lead vs. no lead) served as a within-subjects independent variable.

Prior knowledge, metacognitive awareness, and reading comprehension served as covariates in the repeated measures MANCOVA on cognitive load. Since the analysis involved only two levels of the independent variable, the sphericity and compound symmetry assumptions were not relevant (e.g., Algina & Keselman, 1997). Further, multivariate tests of the repeated measures main and interaction effects are generally thought to be robust to their assumption violations when the design is balanced (Keselman, 1998).

The overall MANCOVA on cognitive load was significant ($F_{(5,12)} = 3.27$, $p < 0.05$), prompting further analysis through a series of univariate repeated measures ANCOVAs. For each of the ensuing ANCOVAs, presence of leads served as the independent variable, and one of cognitive load measures served as the dependent variable. Prior knowledge, metacognitive awareness, and reading comprehension again served as covariates.

The repeated measures ANCOVA with alpha ERD% as the dependent measure reached significance ($F_{(1,16)} = 5.56$, $p < 0.05$, $MS_e = 7.22$). Mean alpha ERD% in the no lead condition ($\overline{X} = 44.67$, $SD = 9.12$) was higher than in the lead condition ($\overline{X} = 36.08$, $SD = 9.24$). Thus, cognitive load appeared to be higher in the no lead condition, as represented by alpha ERD%. No covariates reached significance.

The repeated measures ANCOVA for beta ERD% was also significant ($F_{(1,16)} = 5.76$, $p < 0.05$, $MS_e = 8.82$). Mean beta ERD% in the no lead condition ($\overline{X} = 33.67$, $SD = 8.52$) was higher than in the lead condition ($\overline{X} = 26.27$, $SD = 7.87$). Cognitive load appeared to be higher in the no lead condition, as represented by beta ERD%.

The repeated measures ANCOVA for theta ERD% also reached significance ($F_{(1,16)} = 6.64$, $p < 0.05$, $MS_e = .96$). The absolute value of mean theta ERD% in the no lead condition ($\overline{X} = 16.90$, $SD = 3.43$) was significantly higher than mean theta ERD% in the lead condition ($\overline{X} = 11.83$, $SD = 3.55$). This result also indicated that cognitive load was higher in the no lead condition. No covariates reached significance.

Although the reading time repeated measures ANCOVA approached significance ($p = .08$), the self-reported mental effort repeated measures ANCOVA was not significant ($p > .12$). Reading time in the lead condition was greater than in the no lead condition ($\overline{X} =587.23$, $SD = 116.06$ and $\overline{X} = 571.83$, $SD = 126.20$ respectively). This finding can be explained by the fact that in the lead condition readers had to process the information contained in the leads in addition to the information from the primary text passage and subordinate nodes.

Analysis of Learning Performance Data

The second research question asks whether the use of leads in conceptually rich hypertext affect learning performance A 3 x 2 repeated measures MANCOVA for three dependent measures of learning: a) recall, b) conceptual knowledge, and c) structural knowledge, and with presence of leads as a within-subjects independent variable was used to determine the effect of leads on learning performance. Subjects' scores on the tests of prior knowledge, metacognition, and reading comprehension were used as covariates. This finding indicates that leads did not affect learning.

Effect of Individual Differences on Cognitive Load and Learning

This research study also focused on identifying the effect of interpersonal differences on cognitive load and learning in conceptually rich hypertext. Results from the repeated measures MANCOVAs and ANCOVAs suggested that some of the covariates were explaining significant amounts of variance under certain conditions. The individual differences measures can be assumed to affect cognitive load and learning, if the covariates reached significance in any of these analyses.

Metacognitive awareness was a significant covariate in the overall cognitive load MANCOVA ($F_{(5,12)} = 6.83$, $p < 0.01$) analysis. Metacognitive awareness also reached significance for the beta ERD% ANCOVA ($F_{(1,16)} = 4.63$, $p < 0.05$). Bivariate Pearson product-moment correlation coefficient was used to further examine these relationships. A positive relationship was found between subjects' metacognitive awareness scores and their use of leads to review learning content ($r = .63$, $p < 0.01$). These findings suggest that subjects whose metacognitive skills were better developed tended to use leads as a tool to review information in lead-augmented hypertext.

Another covariate – prior knowledge – was significant for the repeated measures recall ANCOVA ($F_{(1,16)} = 6.81$, $p < 0.05$). A bivariate Pearson product-moment correlation coefficient revealed a positive relationship between subjects' scores on the prior knowledge test and their recall performance in the lead condition ($r = .45$, $p < 0.05$). No additional relationships were found between prior knowledge scores and performance on the recall task in the no lead condition.

Discussion

The study reported here produced several important findings. First, EEG-based cognitive load measures showed a positive effect of leads on decreasing subjects' brain wave activity when accessing new hypertext nodes via leads. However, differences in cognitive load between two experimental conditions were not detected by self-reports of mental effort or the reading time measure. Second, leads did not appear to produce a significant effect on learning outcomes. And, finally, subjects with superior metacognitive awareness appeared to use leads to review learning content.

Effect of Leads on Cognitive Load

Event-related desynchronization percentage of alpha, beta and theta brain wave rhythms accounted for 20 seconds of subjects' reading when they were following links or leads to the new hypertext node. Results of this study demonstrate that this method was useful in detecting subtle fluctuations in brain activity that was presumably associated with the effect of mental integration processes and split attention. Brain activity appeared to be more intense in the no-lead, traditional hypertext condition, which was reflected consistently by alpha, beta, and theta ERD% values. Therefore, EEG-based measures demonstrated that leads may be an effective tool for reducing extraneous load associated with split attention in the context of reading conceptually rich hypertext.

Self-report of mental effort and reading time did not reveal any differences in cognitive load between the two experimental conditions. This latter finding is consistent with the result of the MANCOVA on learning, which showed no effect of leads on the combined performance on the recall task, conceptual and structural knowledge test. Thus, the self-report and reading time measures of cognitive load appeared to be *better indicators of* *learning*. The differences in the results of cognitive load measures used in this study led to further examination of the literature on cognitive load measurement methodology.

Cognitive load has been defined as a theoretical construct that describes cognitive processes that cannot be directly observed. Although some researchers have suggested that cognitive load is represented directly and objectively by brain activity measures like fMRI, ERPs, EEG, and MEG (Brunken, Plass, & Leutner, 2003; Schultheis & Jameson, 2004), so-called direct measurement of cognitive load is problematic. These measures reflect brain activity, and cognitive load can only be *inferred* based on the degree and dynamics of subjects' mental processing.

Brain activity measures used in this experiment were based on Event-Related Desynchronization percentage of alpha, beta, and theta brain wave rhythms. EEG data were collected from two cortex sites that had been demonstrated repeatedly to reflect mental processing associated with working memory operations and interactions of working memory and long-term memory (e.g., Cohen, et al, 1997; Jonides, et al, 1998; Todd & Marois, 2004). However, while the recent findings in neuropsychology and neurophysiology have advanced our understanding of the localization and distribution of various brain functions, many unanswered questions remain. As discussed in the literature review, some of these questions involve the role of hippocampus in mediating working memory and long-term memory processes (Miller, 1991), effects of different types of tasks used in experimental research on human memory (Gevis, et al, 1997; Klimesch, 2006), and, more generally, a need for a unified theory of brain functions (Basar, 2004; Callicott, et al., 1999; Goldman-Rakic, 1996; Zhang, & Linden, 2003).

These unsolved issues create challenges for researchers who work to describe mental processes and attribute brain responses to specific functions of the cognitive system. Thus, even though EEG-based measures used in the present study indicated decreased brain wave activity when accessing hypertext links that were augmented with leads, such a decrease does not necessarily reflect reduced cognitive load. Further, even given the premise that cognitive load is directly represented by brain activity measures, these measures do not allow one to distinguish the types of load that are present in the information processing situation. In fact, none of the currently available measurement techniques allow differentiation between the contributions of intrinsic, germane, and extraneous cognitive load induced by the learning task (Paas, Tuovinen, Tabbers, & van Gerven, 2003).

Similar validity problems arise when measuring cognitive load with self-reports. Although self-report of mental effort appears to be the most widely used method of assessing cognitive load (Paas, Tuovinen, Tabbers, & van Gerven, 2003), it is unclear how a subjective perception of mental effort relates to the use of cognitive resources associated with limited working memory capacity. Subject’s ability to introspect on mental processing has been questioned extensively beginning as early as 1600s (e.g., Francis Bacon as quoted in Meese, 1934). More recently, weaknesses of the self-report methodology were discussed by educational psychologists. For example, working memory processes that affect learning (like assimilation and accommodation) involve interaction with long-term memory schemas, which become automated with practice. Such processes occur outside of conscious awareness and thus are not actively processed in working memory, and may, therefore, be unavailable for introspection or accurate self-monitoring. Consequently, subjects’ self-reports of mental processes may be inaccurate or incomplete (Chao & Salvendy, 1994; Feldon, 2004).

In light of the results of cognitive load measurement in the present study, one could propose that self-reported mental effort and reading time were better indicators of the *overall* cognitive load relative to the learning that occurred. EEG-based measures appeared to be useful in detecting more subtle fluctuations in *instantaneous* load associated with split attention, when subjects were following links or leads to the new node. However, based on concerns with cognitive load measures described above, caution should be used in drawing conclusions from these data.

Effect of Leads on Learning Performance

Results of the MANCOVA on the three dependent measures of learning performance indicated that learning was not affected by leads. Multiple explanations may be proposed as to why leads did not produce an effect on learning. One reason might be the complexity of learning materials used in this study and the associated levels of intrinsic cognitive load. Scores on both the pre-test of prior knowledge and the post-tests of learning demonstrated that the learning theory texts may have been fairly difficult for the subjects' to integrate into the knowledge base. In addition to the complexity of the learning materials, subjects may have experienced low levels of engagement with the content–perhaps the texts on educational psychology did not evoke genuine interest in the subject matter.

The *redundancy effect* generated by cognitive load theory (Sweller & Chandler, 1991), provides another possible explanation for why leads, which were originally hypothesized as a useful tool for reducing extraneous load associated with split attention, did not affect learning performance. The redundancy effect occurs when the learner is required to process nonessential, redundant information (Yeung, Jin, & Sweller, 1997). The result is a decrease in learning performance due to higher levels of extraneous load associated with processing redundant information elements.

The negative effects of redundant information have been discussed in different contexts for nearly 70 years. As with many other scientific findings, however, this effect seems to have been discovered, forgotten, and then rediscovered again (Sweller, 1993; Sweller & Chandler, 1991). Interestingly, the redundancy effect has not become widely recognized and discussion in the instructional design field has been rare. One explanation for this paradox might be that the effect of redundancy is counterintuitive (Sweller, 1993). Given Thorndike's law of exercise (1898), which essentially states that practice makes perfect, and a general sense of studying by reading and re-reading, redundant information should effectively promote learning, and if it is not effective, at worst it should be neutral.

In an extensive review of the redundancy effect literature, Yeung and colleagues (1997) identified one of the first demonstrations of the redundancy effect in a study involving teaching young children to read (Miller, 1937). In this study it was found that presenting children with a word that was associated with a picture (e.g., the word "cat" associated with a picture of a cat) was less effective in teaching children to read than presenting the word alone. Other work focused on students learning information from a textbook, and showed that students could learn more from summaries of textbook chapters than from the full chapter and summary presented together (Reder & Anderson, 1980, 1982). More recently, results of studies framed in cognitive load theory demonstrated that a diagram alone was superior to a diagram with text that recapitulated the information in the diagram (Chandler & Sweller, 1991), and presenting identical visual and auditory text was found less effective than the auditory text alone (Craig, Gholson, & Driscoll, 2002; Kalyuga, Chandler, & Sweller, 2000; Mayer, Heiser, & Lonn, 2001).

Negative effect of redundancy was reported in a study aimed at determining the effect of explanatory notes on the learning performance of 24 fifth-graders in an English language classroom (Yeung, Jin, & Sweller, 1997). The explanatory notes in this study were functionally similar to leads because they were integrated into traditional text passages to enhance comprehension of the text. Results of this study demonstrated that the combined use of commentary notes and vocabulary notes did not produce an effect on learning performance. The authors concluded that even though the combination of vocabulary and commentary notes integrated within a text passage may have provided the readers with direct access to the meanings of both words and sentences, information contained in these explanatory notes was to some extent redundant and so of limited benefit. Measures of cognitive load in the studies reviewed here showed that cognitive load was higher in the redundancy condition. Increased load and decreased learning performance were therefore attributed to the effect of extraneous load associated with processing redundant information.

In the present study, a key consideration during the design phase was that texts in experimental conditions must be equivalent in terms of the learning content that they present. Attributing enhanced learning performance or decreased cognitive load to the effect of leads would have been unfair, if the leads had included summaries that were not available in the traditional hypertext condition. To design treatments that were consistent relative to the content, all leads contained only information that was already present in the linked nodes, both in the traditional and lead-augmented hypertext condition. Consequently, summary information contained in the linked node *repeated* information from the lead that subjects had just read in the lead-augmented hypertext condition, which may have affected the dynamics of their cognitive load and learning.

Self-reports of mental effort, reading time, and measures of learning performance used in the present experiment were consistent in demonstrating that leads did not produce *any* detectable effect on overall cognitive load, – nor did they affect learning performance. Processing redundant summaries in hypertext nodes may have required the use of learners' cognitive resources, and any benefits associated with reducing split attention and extraneous load through the use of leads might have been negated by the cognitive effort required to process redundant information. Such cognitive effort may have raised the amount of extraneous load due to the redundancy effect, overriding the positive effect of the use of leads to reduce split attention.

While increasing extraneous load, redundant information may have also effectively decreased germane load that is required for learning to take place. Germane load occurs when the learner expends cognitive resources to analyze and integrate new content relative to existing knowledge. *Cognitive dissonance*, or what Piaget refers to as *disequilibration* (Festinger, 1957; Piaget, 1951), occurs when there is an inconsistency between what is already known and new information. This state of uncertainty is what drives the learning process; learners actively construct consistency among their conceptions to eliminate the uncomfortable dissonance (Aronson, 1969). Cognitive dissonance may be regarded as the primary source of germane load in the context of cognitive load theory. However, when cognitive dissonance is not present, the learner is in the comfortable state of *cognitive equilibrium* where germane load and learning are not likely to occur since there is no need to modify existing conceptions. Learning content loses its novelty, which impacts levels of interest and motivation and may trigger a metacognitive response to ignore redundant information. Thus, while cognitive load literature seems to focus on discussing the redundancy effect relative to *increased extraneous load*, processing of redundant information that does not disrupt cognitive equilibrium may also produce a negative effect associated with *decreased germane load*.

In the context of the present study, learners may have experienced a decrease in germane load when they had to process redundant information that was contained at the end of linked nodes in the lead-augmented hypertext condition. Readers were required to process the lead that summarized the linked node before accessing this node when reading information from lead-augmented hypertext. As such, they were able to begin interrelating concepts from the primary text passage and the linked node, while the primary passage was still visible. Results of the EEG-based measures indicated that the amount of brain activity at the instance of subjects' accessing linked nodes in the lead-augmented condition was decreased, which may reflect a decrease in cognitive load. Thus, more cognitive resources appeared to be available for germane processing of the learning content in the lead-augmented condition. However, when learners approached the concluding sentence in each node that contained node summary, they encountered information that they had previously read in the lead. Learners had already integrated this content, and while there may have been an increase in extraneous load associated with processing this redundant information, levels of germane load likely plummeted due to a loss of cognitive dissonance and interest in this information. Therefore, the possible benefits accrued through the use of leads might have been mediated by the negative effect of increased extraneous load and decreased germane load that were caused by redundant summaries. In fact, during oral debriefing subjects

(12/20) indicated that "leads would have been more helpful if they had not repeated information from the linked page."

Metacognitive Awareness and Use of Leads to Review Information

In this study, all subjects were given the opportunity to use the leads to glean information from the nodes linked to the main text passage. In addition to using leads during the *initial* reading of the text, students with higher self-reported metacognitive skills also tended to use the leads to review information from the nodes *after* they finished reading the text. These students reviewed the primary passage, while also rolling their mouse over the lead-augmented links to recall text in the linked nodes. This pattern in the use of leads might indicate that students with higher metacognitive skills appeared to focus more than their counterparts on assessing their current knowledge on the topic (monitoring cognition) and reviewing the text to recall information (regulating cognition).

Instructional designers have introduced various tools and strategies to assist learners with metacognitive decisions. In one study, students' metacognitive thinking was encouraged with the help of automated prompts in the form of questions (Kauffman, 2002). Results of this study demonstrated that subjects in the control group who didn't have to respond to the self-monitoring prompts exhibited lower performance on a knowledge transfer posttest. Another study used human tutors trained in self-regulated learning techniques to encourage learners' metacognitive strategies in a hypertext-based learning environment (Azevedo et al, 2002). Students who had been exposed to this type of metacognitive training performed better on post-tests of learning than those who had been offered no training. Similarly, a study might determine whether metacognitive assistance in the uses of leads in hypertext has an effect on students' cognitive load and learning.

Implications

The findings of the present study create implications for further research on the optimization of cognitive load and learning in the context of instructional hypertext. As the EEG data in the present study showed, the split attention effect in hypertext-assisted learning may have been decreased with the help of leads. It is important, however, to make sure that the information contained within the lead enhances rather than reproduces information that is already present in the linked node. Further research could determine whether the use of leads might preserve the positive effect on reducing split attention, leaving additional cognitive resources available for germane processing of the learning content, when the redundancy effect is removed.

Considering cognitive load theory's distinction of intrinsic, extraneous, and germane load, it is important to note that so far researchers have measured the overall cognitive load and have not been able to use any of the measurement techniques to differentiate between these three cognitive load components. Thus, more research is necessary to develop, refine, and test cognitive load measures relative to the discrimination between contributions of the intrinsic, extraneous, and germane load types. For example, self-report measures might prove useful in inferring the amount of intrinsic cognitive load because they appear to relate directly to the difficulty of the learning materials. Thus would hold true relative to the results of this study. The treatments were designed to contain texts of the same level of complexity, and all subjects were novices in the content area. So, no differences in cognitive load as indicated by self-reports might indeed indicate no differences in intrinsic load. Similarly, a reading time measure may potentially provide information about the germane load present in the information-processing situation because it might reflect subject's levels of engagement with the content. Another promising approach that has recently emerged in the literature deals with an exploration of multi-dimensional efficiency of instructional conditions (Tuovinen & Paas, 2004). These researchers acknowledge that a meaningful interpretation of cognitive load can only be given in the context of its associated performance level, and propose multi-dimensional methods, which combine the tests of learning effort, test effort, test performance, time on task, and other measures of learning and cognitive load.

Results of this study indicated that summary leads did not produce an effect on learning. Thus, additional research aimed at improving hypertext-assisted learning might determine the effect of different *types* of leads on decreasing extraneous load and increasing germane load and the resulting learning. A definition lead might prove more useful in the context of a knowledge acquisition task, while a summary lead could help learners search for information in hypertext more effectively and efficiently. Other types of leads that may have potential benefits for learning in a hypertext-based environment are example leads, quote leads, or contrast leads. Each of these types of leads provides a different kind of support with text coherence, and might produce an effect on both learning outcomes and student motivation in various learning situations.

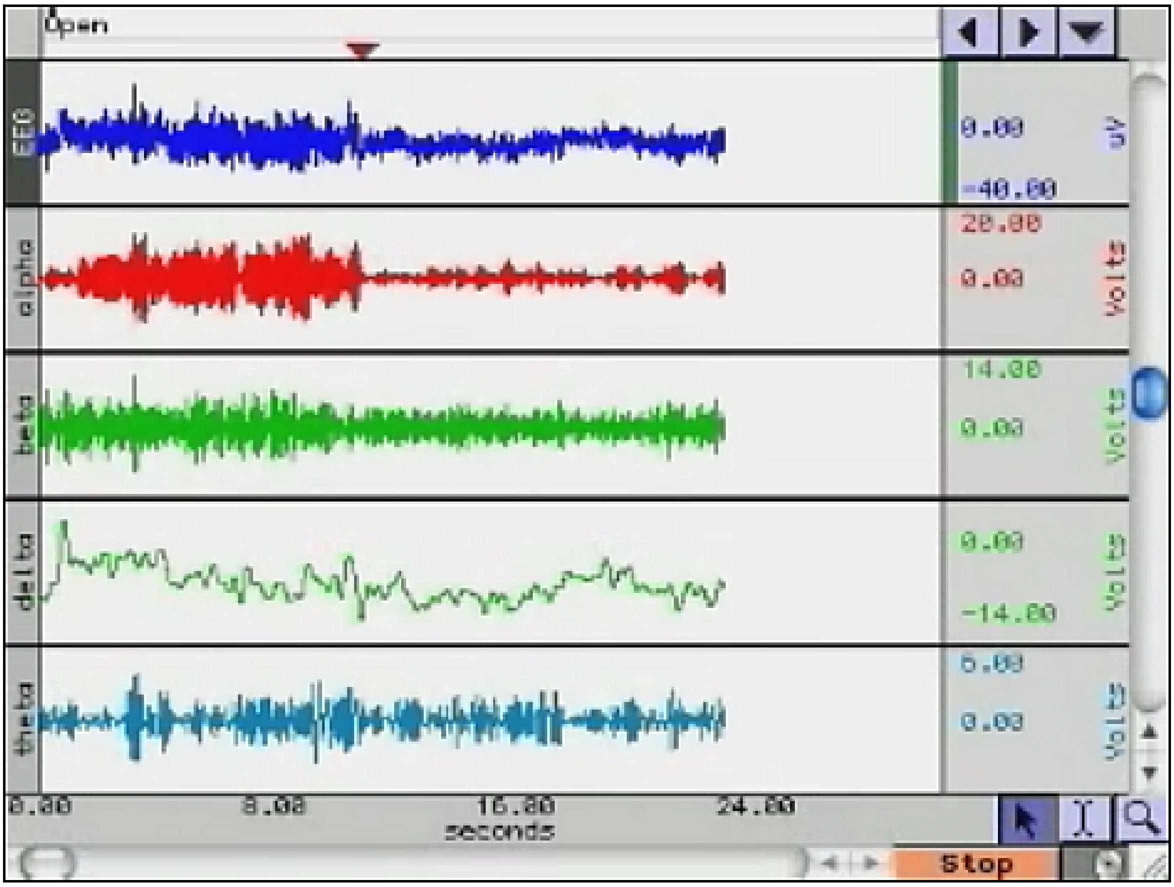
In addition to studying the effect of variable textual content contained within the lead, it might be useful to determine the role of various lead presentation media on learning and cognitive load. Much research has been done on the effects of using pictures, diagrams, animations, and sound in multimedia-assisted learning. And while the use of audio in hypertext-based materials is typically discouraged (Nielsen, 2006), image leads or diagram leads might introduce benefits in certain learning contexts (e.g., physics, engineering, art and design etc.)

Another implication stems for the use of leads to review information that was revealed by the results of this study, and highlights the need to explicate to the learners the benefits of using leads to review information and to inform navigational decisions. A study involving the use of leads in instructional hypertext might determine whether metacognitive assistance or training affects the patterns of using leads and has an effect on learning and cognitive load.

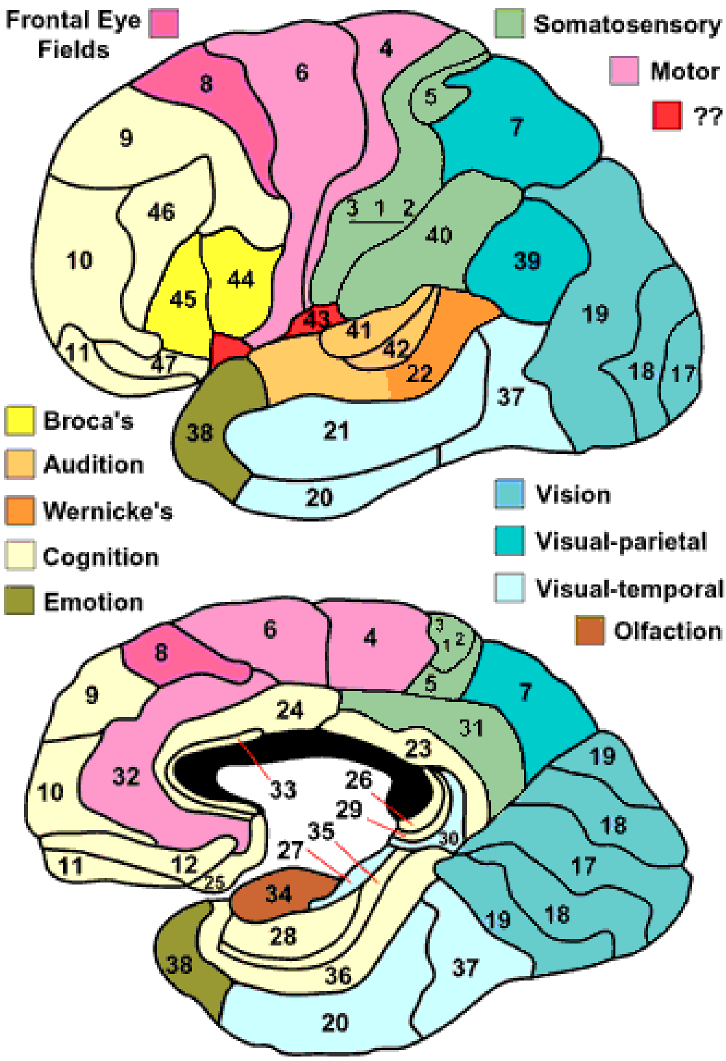
Conclusion

Overall, the results of this study complement other findings in the literature on the use of tools that are functionally similar to leads. Earlier studies supported the positive effect of node previews and link comments on improving navigational processes like searching and failed to show positive effects on learning (e.g., Betrancourt & Bisseret, 1998; Schweiger, 2001). Similarly, measures of overall cognitive load and learning performance used in the present study did not detect differences between lead-augmented and traditional hypertexts. Results of the EEG-based measures demonstrated that leads appeared to reduce brain activity associated with split attention when subjects were accessing lead-augmented links. However, complexity of the texts and redundant information contained in the nodes may have decreased the potential benefits introduced by leads due to increased extraneous load and decreased germane load. Whereas the benefits of leads relative to cognitive load and learning performance may have been negated by the redundancy effect, learners with better developed metacognitive skills tended to use leads as a tool to review information in the linked nodes while revisiting content in the primary text passage. Thus, leads appear to be a potentially useful tool for supporting metacognitive decisions and reducing split attention, and further research is needed to determine the effect of leads on cognitive load and learning when the redundant information is removed.

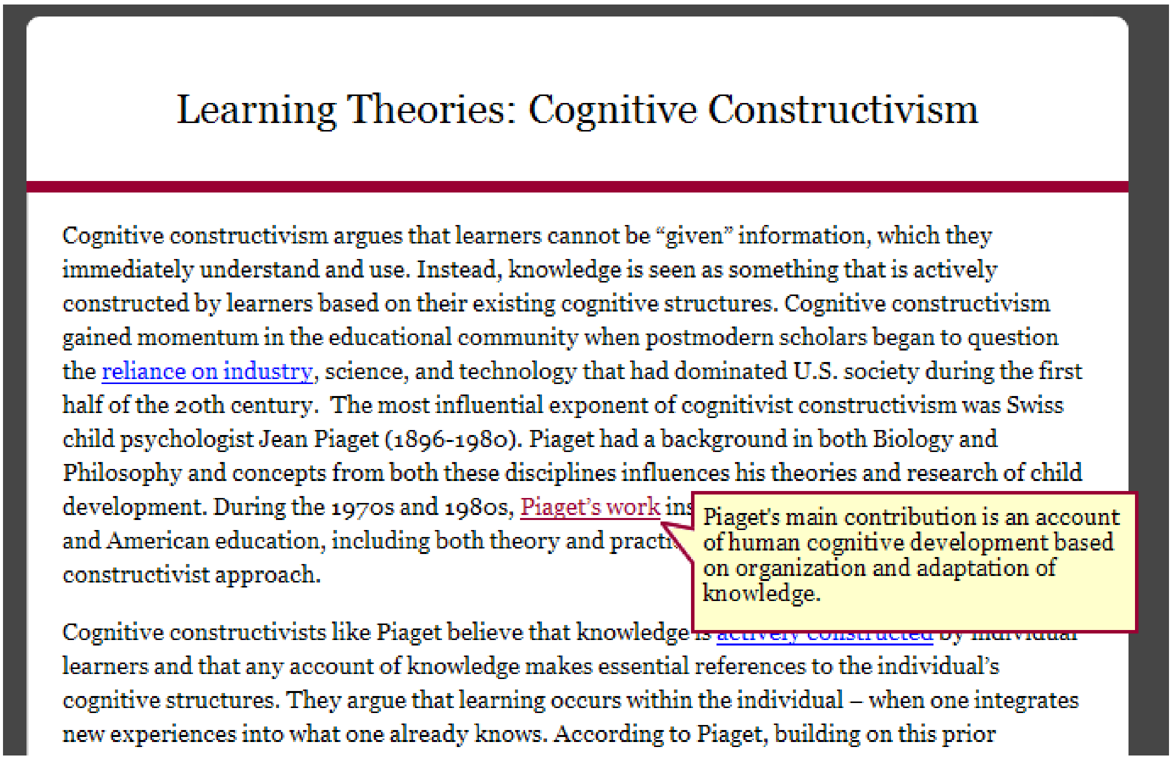
Appendix A: Alpha Suppression



Appendix B: Brodmann Map of the Human Brain



Appendix C: A Screenshot of Lead-Augmented Hypertext



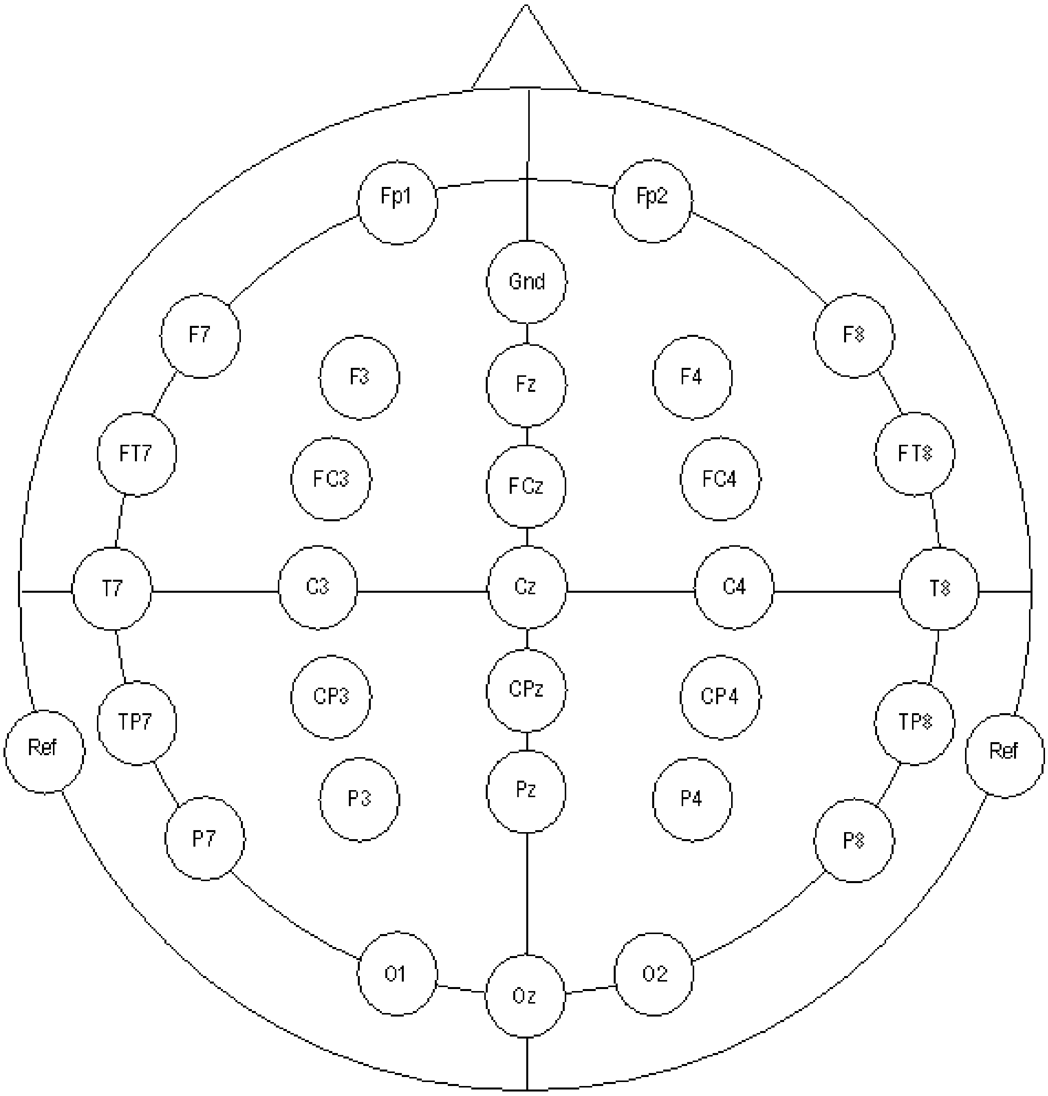
Learning Theories: Cognitive Constructivism

Cognitive constructivism argues that learners cannot be "given" information, which they immediately understand and use. Instead, knowledge is seen as something that is actively constructed by learners based on their existing cognitive structures. Cognitive constructivism gained momentum in the educational community when postmodern scholars began to question the reliance on industry, science, and technology that had dominated U.S. society during the first half of the 20th century. The most influential exponent of cognitivist constructivism was Swiss child psychologist Jean Piaget (1896-1980). Piaget had a background in both Biology and Philosophy and concepts from both these disciplines influences his theories and research of child development. During the 1970s and 1980s, Piaget's work ins
and American education, including both theory and practi
constructivist approach.

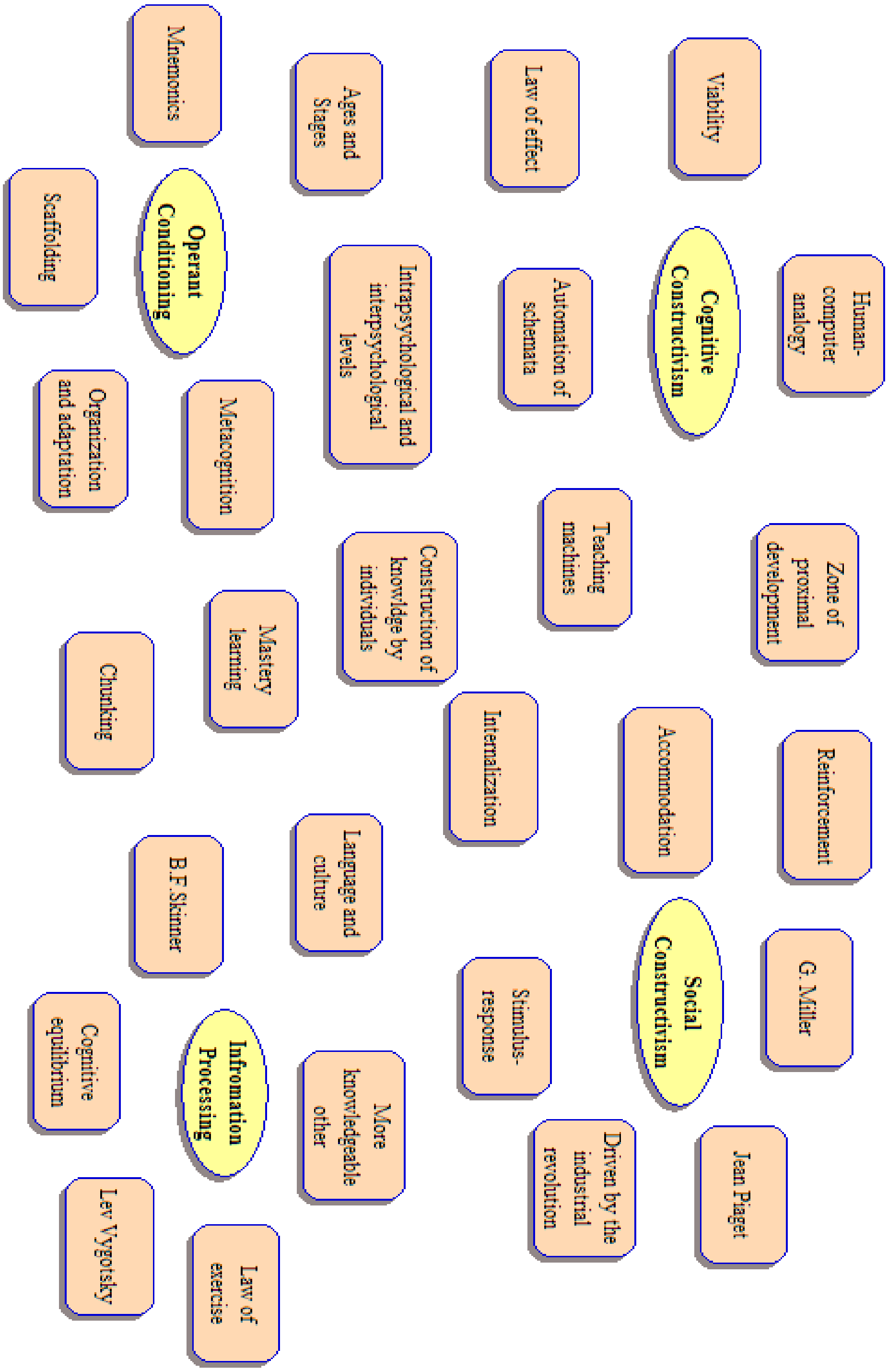
Piaget's main contribution is an account of human cognitive development based on organization and adaptation of knowledge.

Cognitive constructivists like Piaget believe that knowledge is actively constructed by individual learners and that any account of knowledge makes essential references to the individual's cognitive structures. They argue that learning occurs within the individual – when one integrates new experiences into what one already knows. According to Piaget, building on this prior

Appendix D: The International 10-20 System for Electrode Placement (Jasper, 1958)



Appendix E: Structural Knowledge Task Template



Appendix F: Conceptual Knowledge Test

1. Equilibration involves:
    a. Active use of accommodation to regain cognitive balance
    b. Assimilation of information that doesn't conflict with prior knowledge
    c. Automation of schemata
    d. Optimization of the working memory

2. The "law of effect" maintains that:
    a. when a connection between a stimulus and response is positively rewarded it will be strengthened
    b. when between a stimulus and response is negatively rewarded it will be weakened
    c. the more a stimulus-response bond is practiced the stronger it will become
    d. both a and b

3. The "ages and stages" theory was developed by:
    a. Edward Tolman
    b. Lev Vygotsky
    c. George Miller
    d. Jean Piaget

4. Schemata are defined as:
    a. Memory structures that help humans remember information
    b. Sets of stimulus-response bonds organized under a common topic
    c. Modules used in the development of teaching machines
    d. Layers of the zone of proximal development

5. The concept of viability was developed as an alternative to the concept of:
    a. Fact
    b. Truth
    c. Reality
    d. Practice

6. Cognitivist teaching methods focus on:
    a. Helping students assimilate and accommodate new material
    b. Use of positive reinforcements and consistent repetition of new material
    c. Cognitive strategies for effective encoding and retrieval of information
    d. Promoting interaction and collaboration with peers and instructors

7. Operant conditioning is defined as:
    a. Use of instructional scaffolding to promote learning
    b. Use of prior knowledge and experiences to make sense of new material
    c. Use of consequences to modify the occurrence and form of behavior
    d. Use of cognitive strategies to enhance encoding, storing and retrieval of information

8. According to social constructivists, language is important because:
    a. It is a method of transferring information to learners
    b. It is the framework through which we experience, communicate, and understand reality
    c. It is a mechanism for encoding, storing and retrieval of information
    d. It marks a progression of children through the stages of cognitive development

9. Cognitive constructivists hold that :
    a. Knowledge resides within the individual
    b. Knowledge extends beyond the bounds of the body into social environment
    c. Knowledge can only be measured through observable behavior
    d. Knowledge is organized and stored in computer-like memory structures

10. Social constructivism developed under the influence of:
    a. Soviet views on the role of community and culture
    b. Advancements brought about by the industrial age
    c. Questioning of the reliance on science and technology
    d. Development of first computers

11. Lev Vygotsky's primary contribution to learning theory was in:
    a. Account of human learning based on his research in animal psychology
    b. Emphasis on the interpsychological level in human development
    c. Explanation of human learning through the computer metaphor
    d. Development of the concept of schema

12. The concept of internalization represents:
    a. Forming of stimulus-response associations
    b. Automation of schemata
    c. Transmission of information from working memory into the long-term memory

   d. Using symbolic systems like language to understand the shared knowledge of a culture

13. George Miller is credited with:
    a. Proposing the concept of operant conditioning
    b. Proposing the idea that human short-term memory has very limited capacity
    c. Proposing the concept of schema
    d. Proposing the concept of zone of proximal development

14. A "more knowledgeable other" is:
    a. The teacher
    b. A more advanced peer
    c. Anybody with more knowledge or experience
    d. A parent

15. The main principle behind the concept of a teaching machine is:
    a. It allows the learner to view a number of resources on the topic
    b. It tests learner's understanding of the topic via multiple choice tests
    c. It allows learners to explore an ill-structured, Web-like learning environment
    d. It requires the learner to view a resource, answer a question and gives immediate feedback on the quality of response

16. Scaffolding involves:
    a. Provision of sufficient supports, resources and guides
    b. Practice and repetition
    c. Teaching of memory strategies
    d. Demonstrating ways to solve problems

17. According to cognitive constructivists, learning is based on:
    a. Organization and adaptation of knowledge
    b. Law of effect and law of exercise
    c. Effective encoding and retrieval of information
    d. Practiced stimulus-response bonds

18. Social constructivists hold that:
    a. Learning occurs within the individual, when one integrates new experiences into what one already knows
    b. Associations external to the mind form between events and actions
    c. Human mind is an information processing system

   d. Range of knowledge and skills that can be developed with adult guidance or peer collaboration exceeds what can be attained alone

19. Development of complex thinking, in the information processing view, involves:
   a. Active use of assimilation, accommodation, and equilibration of information
   b. Automation of schemata
   c. Automation of stimulus-response associations
   d. Optimization of the working memory

20. According to social constructivists, human development is primarily the result of:
   a. Influence of the learned cause-effect relationships
   b. Influence of the language and culture
   c. Influence of the assimilating, accommodating, and equilibrating information
   d. Influence of the automation of schemata

21. Operant conditioning developed under the influence of:
   a. Spread of socialist views in eastern Europe
   b. Industrialization of the American society
   c. Questioning of the reliance on science and technology
   d. Development of first computers

22. The human-computer metaphor is based on observation that
   a. Both computers and humans engage in learning stimulus-response associations
   b. Both computers and humans are products of the society and culture
   c. Both computers and humans engage in encoding, storing, and retrieval of information
   d. Both computers and humans engage in cognitive processes like reasoning

23. B.F. Skinner’s major contribution was:
   a. Developing the concept of zone of proximal development
   b. Developing the concept of schema
   c. Developing the concept of operant conditioning
   d. Developing the concept of cognitive equilibration
24. Information Processing theory developed as a response to:
   a. Limitations of the behaviorist approach
   b. Limitations of the social constructivist approach
   c. Limitations of the cognitive constructivist approach
   d. Changes in the society brought about by the Industrial Age

25. Much of the teaching inspired by operant conditioning is based on the principles of:
    a. Cognitively-guided instruction
    b. Mastery learning
    c. Discovery learning
    d. Collaborative learning

26. Cognitive constructivists believe that knowledge consists of:
    a. A series of stimulus-response associations
    b. Mental representations derived from past experiences
    c. Cognitive structures internalized through social interactions
    d. Information accumulated through formal education

27. Metacognition refers to:
    a. Process of retrieving information using mnemonics
    b. Process of reflecting on one's stimulus-response associations
    c. Process of reflecting on one's cognitive strategies
    d. Process of reflecting on one's cognitive abilities

28. Operant conditioning favors teaching methods that employ:
    a. Consistent repetition necessary for effective reinforcement of response patterns
    b. Consistent repetition necessary for effective encoding of information in memory
    c. Punishment as a way of discouraging unwanted behaviors
    d. Both b and c

29. A cognitive constructivist teacher's role is to:
    a. Encourage learners to interact with one another and share cultural values
    b. Design sequencing of learning tasks and reinforcement schedules
    c. Guide learners in exploring, experimenting, and reflecting on the new material
    d. Make effective use of teaching machines to improve mastery learning

30. According to operant conditioning, effective reinforcement schedule requires:
    a. Small, progressive sequences of tasks
    b. Consistent repetition of the material
    c. Continuous positive reinforcement
    d. All of the above

31. According to the information processing theory, learning should include:
    a. Presenting learners with opportunities to construct and share knowledge via social interactions
    b. Presenting learners with appropriate behavioral responses to specific stimuli and to reinforce those responses
    c. Presenting learners with developmentally appropriate activities that enhance organization and adaptation of knowledge
    d. Presenting learners with cognitive activities that encourage activation and automation of schemata

32. Reinforcement is defined as:
    a. A consequence that causes a behavior to occur with greater frequency
    b. A consequence that causes a behavior to occur with less frequency
    c. Lack of any consequence following a response
    d. Automation of memory structures

33. Chunking is a learning strategy related primarily to:
    a. Operant conditioning
    b. Cognitive constructivist theory
    c. Social constructivist theory
    d. Information processing theory

34. Jean Piaget's main contribution is:
    a. Demonstration of the mental maps that rats used to find their way through a maze
    b. Emphasis on the role of language in a child's cognitive development
    c. Account of human cognitive development based on organization and adaptation of knowledge
    d. Development of the first "teaching machine"

35. Human working memory has the capacity to store:
    a. 3 ± 2 information units
    b. 10 ± 2 information units
    c. 7 ± 2 information units
    d. 5 ± 3 information units

36. Mnemonics are methods based on the principle that:
    a. Our mind remembers data attached to meaningful information more easily than that occurring in meaningless patterns

b. Our mind remembers data attached to practiced stimulus-response bonds more easily than that occurring in meaningless patterns
c. Our working memory has a very limited capacity
d. There are no known limits to the capacity of our long-term memory

37. From the social constructivist perspective, people come to understand the reality by:
    a. Comparing their version of truth with that of their peers
    b. Constructing viable interpretations of the reality based on prior experiences
    c. Operating on the environment and making connections between events and actions
    d. Forming, and automating mental representations of the aspects of reality

38. Cognitive constructivism developed as a response to:
    a. Limitations of the social constructivist approach
    b. Dissatisfaction with the human-computer analogy promoted by information processing theorists
    c. Popularity of Jean Piaget
    d. Need for workers who could develop creative solutions to complex problems

39. "Law of effect" and "law of exercise" were developed by:
    a. Edward Tolman
    b. Jean Piaget
    c. Edward Thorndike
    d. B.F. Skinner

40. Zone of proximal development refers to:
    a. Level at which children experience the world through movement and senses
    b. Level at which the learner is capable of solving problems independently
    c. Level at which children develop abstract reasoning
    d. Level that the learner is capable of reaching under the guidance of teachers or in collaboration with peers

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