The effects of the number of links and navigation support on cognitive load and learning with hypertext: The mediating role of reading order

R. Ignacio Madrid [a,*], Herre Van Oostendorp [b], Mari Carmen Puerta Melguizo [b]

[a] *Department of Experimental Psychology and Physiology of Behaviour, University of Granada, Campus de Cartuja, s/n, 18071 Granada, Spain*
[b] *Center for Content and Knowledge Engineering, Institute of Information and Computing Sciences, Utrecht University, Padualaan 14, 3584 CH Utrecht, The Netherlands*

ARTICLE INFO

ABSTRACT

Problems in learning with hypertext systems have been claimed to be caused by high levels of disorientation and cognitive load. This was recognized by DeStefano and LeFevre [DeStefano, D., & LeFevre, J. -A., (2007). Cognitive load in hypertext reading: A review. *Computers in Human Behavior, 23*(3), 1616–1641.] who predicted an increase of cognitive load and impairment of learning for hypertexts with a higher number of links per page. From a practical perspective, several navigation support techniques, such as providing link suggestions, have been proposed for guiding learners and reducing cognitive overload. In an experiment, we tested DeStefano and LeFevre's predictions as well as the usefulness of link suggestions. Participants used different versions of a hypertext, either with 3-links or 8-links per page, presenting link suggestions or not. We tested their cognitive load and learning outcomes. Results showed that there was a benefit of using link suggestions for learning, but no effect of number of links on learning was found. Moreover, the effects of our manipulations on cognitive load were mediated by the reading order that participants selected. Implications for research and the design of navigation support systems are discussed.

1. Introduction

Hypertext is becoming one of the most important tools for acquiring information, not only because it is used extensively on the Internet, but also in many learning environments such as CD's or DVD's in the form of Encyclopaedias, Educational Hypermedia or Games.

Searching and navigating (also called browsing or surfing) are the main activities that users perform to find information in hypertext systems. By navigating, users select a reading order, starting on a particular information unit (page) and continuing through the links that lead them from that page to other information units. Navigation can be directed by different goals. Sometimes, the user may want to find some specific information, but very frequently people navigate with the more open goal of comprehending the information and learning from different sources. This is often the case of the hypertext systems used in learning environments as educational hypertexts. By navigating, users select their own reading order, which may influence its cognitive load and learning results. We will explore these issues more deeply in the current study.

Learning with hypertexts has two problems that limit its usefulness: (1) regarding the navigation process, people suffer disorientation and cognitive overload (Conklin, 1987; Kim & Hirtle, 1995), (2) regarding comprehension and learning, there is no conclusive experimental evidence that probes that the learning experience is better with hypertexts than with traditional systems such as books (Chen & Rada, 1996; Dillon & Gabbard, 1998; Shapiro & Niederhauser, 2004). These two problems seem to be related, since some evidence exists that shows that disorientation leads to worse learning and performance (Ahuja & Webster, 2001; Puerta Melguizo, Lemmert, & Van Oostendorp, 2006) and high cognitive load in hypertext systems may be responsible for comprehension problems (DeStefano & LeFevre, 2007).

In this study we focus on this latter aspect: the relation between cognitive load imposed by hypertext design features and learning results. With this purpose we analyze the effect of the number of links presented on the navigation menu on cognitive load, reading order and learning outcomes. At the same time, we will test the usefulness of navigation support in the form of link suggestions for reducing cognitive load and enhancing learning.

2. Learning with hypertext

In this section, we will present research findings about comprehension and learning with hypertext systems. Firstly, we start describing the Cognitive-Load Theory and its predictions on hypertext comprehension and learning. We continue describing the

* Corresponding author. Tel.: +34 958243767; fax: +34 958246239.
E-mail address: nmadrid@ugr.es (R. Ignacio Madrid).

Construction–Integration (C–I) model of text comprehension and show some evidence obtained in hypertext comprehension within this framework. Finally, we will show some proposals to enhance readers' performance with these systems mainly through navigational support.

2.1. Cognitive load and learning with hypertext

Cognitive load is a multidimensional construct that refers to how much load is imposed to a learner's cognitive system by a certain task. Cognitive-Load Theory (Kirschner, 2002; Paas & Merriënboer, 1994; Sweller, 1988) assumes a working-memory architecture (Baddeley & Hitch, 1974; Baddeley & Logie, 1999) that can be viewed as a system of limited capacity that can only handle a limited number of elements at the same time. If the cognitive load of a task (or various tasks) exceeds the limits of working memory then performance gets seriously affected (DeStefano & LeFevre, 2007; Xie & Salvendy, 2000). Working memory plays a very important role in comprehension processes since it has to keep active the partial products of reading while providing a link with long-term memory (Van Dijk & Kintsch, 1983; Kintsch, Patel, & Ericsson, 1999).

There is some evidence showing that the role of cognitive load is important for hypertext comprehension. Lee and Tedder (2003) found that readers with high working-memory capacity had a better recall of content when using hypertext compared with those of low working-memory capacity. Correspondingly, there is a claim that cognitive requirements of hypertext exceed those of linear text (Conklin, 1987; DeStefano & LeFevre, 2007; Tardieu & Gyselinck, 2002). However, there is no agreement about this, and some authors think that there is not a greater need of cognitive resources with hypertext, but merely a different balance of resources (Wenger & Payne, 1996).

Cognitive-Load Theory explains how instructional design can affect learning. It makes a distinction between intrinsic, extraneous and germane cognitive load. Intrinsic cognitive load is related with the inherent nature of the materials to be learnt (interactivity between elements) and prior knowledge (PK). Extraneous load (ineffective for learning) is the effort required by poorly designed tasks, while germane cognitive load (effective for learning) concerns activities related with the construction of schemas and automation leading to higher levels of comprehension. Extraneous and germane cognitive loads depend on instructional design and through the design, these can be reduced or enhanced. Since the total amount of cognitive load imposed by a hypertext task has to stay within the limits of working-memory capacity, a bad design can increase extraneous cognitive load too highly, leading to navigation and comprehension problems and to impairment in reading performance.

DeStefano and LeFevre (2007) have claimed recently that problems on hypertext reading can be caused by the cognitive load that users suffer while following links. In their revision of the literature, DeStefano and LeFevre found better performance when the number of link's options is reduced (Jacko & Salvendy, 1996; Landauer & Nachbar, 1985; Parush, Shwartz, Shtub, & Chandra, 2005). They hypothesized that cognitive load may be influenced either directly or indirectly. The direct influence occurs during the link selection process, when readers encounter a link and have to make a decision on whether to follow it or not; this decision requires extra cognitive resources in comparison to linear reading where no decision need to be made. The indirect influence occurs during reading, when the link followed leads to semantically un- or less related text and subsequently to an interruption of the comprehension process that requires extra cognitive resources. In the next section, we will describe how hypertext comprehension processes occur in the light of one of the most accepted theories, the Construction–Integration model of Kintsch (1988, 1998).

2.2. Comprehension and learning with hypertext

To contextualize hypertext effects on comprehension and learning, we will start by considering the Construction–Integration (C–I) model of text comprehension (Kintsch, 1998). This model conceives comprehension as a process of forming a coherent mental representation from the text. This is performed via a cyclic procedure composed of two phases: construction and integration. In the construction phase, a network of interrelated elements extracted from text is added to working memory and combined with the information that was present there before. During integration a spreading activation process selects the most activated elements of the network. At the end of the process, the most activated nodes are stored in working memory to be available in the next cycle. Therefore, reading is carried out in the context of the previously read text elements.

According to the C–I model, various mental representations are constructed during reading, being the textbase and situation model the most important for learning. The textbase is a mental representation of the propositions contained in the text. The situation model is considered the deepest mental representation, and it is formed when the textbase is integrated with prior knowledge. There are several factors that are important for situation model construction; text coherence and prior knowledge are the most important ones. By text coherence we mean the extent to which a reader is able to understand the relations between ideas expressed in a text (Britton & Gülgöz, 1991). There are text characteristics that contribute to text coherence, like the explicitness to which the concepts, ideas, and relations appear within a text. When readers with low domain knowledge read a highly coherent text they construct better situation models than when they read low coherent ones. On the other hand, if the propositions of two text fragments do not share arguments, bridging inferences must be made by accessing background knowledge in order to fill in the lack of information. Since making inferences consumes cognitive resources, the difficulty is even higher for low knowledge readers (Graesser, McNamara, & Louwerse, 2003; Louwerse, 2002; Louwerse & Graesser, 2004; McNamara & Kintsch, 1996; McNamara, Kintsch, Songer, & Kintsch, 1996).

At this point it may be useful to distinguish between text memory and learning from text and the way in which they are related with different comprehension levels. Even though a text can be recalled only from textbase, this does not imply a deep level of understanding. For learning from text it is necessary to elaborate the text content from prior knowledge and to integrate it, achieving a good situation model (Kintsch, 1994).

Comprehension and learning with hypertext seem to follow the same rules as linear texts, except for the fact that readers can select their own reading order by deciding what links to follow. Reading order is an important characteristic of hypertext reading and has a consistent result on learning. By reading order, the coherence between chosen text sections is modifiable, so if learners decide to read the content in a low coherent way their learning is impaired (Salmerón, Cañas, Kintsch, & Fajardo, 2005; Salmerón, Kintsch, & Cañas, 2006a). This effect on learning is caused by what we call the coherence of the reading order, which can be defined as the degree in which the reader's navigation path (or reading order) follows a coherent line of arguments or ideas. Salmerón et al. (2005) gave support to this idea when they showed that low prior knowledge readers who selected a reading order with high text coherence between their visited information nodes constructed a better situation model than those who selected a low coherent reading order. No effect of text coherence was found on textbase.

In general, low prior knowledge students are more prone to have difficulties with navigation and comprehension of hypertext (Amadieu, Tricot, & Mariné, 2006; Chen, Fan, & Macredie, 2006; Lawless, Schrader, & Mayall, 2007; Muller-Kalthoff & Moller, 2006). Since promoting coherent hypertext reading helps low prior knowledge readers with learning, several navigation support systems have been proposed to assist readers with selecting a coherent reading order (McNamara & Shapiro, 2005; Salmerón, Kintsch, & Cañas, 2006b). In the next section, we will explore the benefits of these systems.

2.3. How hypertext performance can be enhanced through navigational support

To assist less advantaged users, some hypertexts and websites offer navigational support (i.e. overviews, concept maps, link suggestions, etc.). Navigation support is claimed to reduce disorientation and cognitive load (Brusilovsky, 2004; Puerta Melguizo, Van Oostendorp, & Juvina, 2007).

One way of giving navigational support is by providing link suggestions to help users to select among link alternatives (Fig. 1 shows how the suggested link is marked with a double arrow "≫" in our experiment). Link suggestions have been shown to enhance coherence formation (McNamara & Shapiro, 2005; Van Oostendorp & Juvina, 2007). For example, Van Oostendorp and Juvina (2007) used link suggestions to help users in a navigation task. They highlighted the relevant links based on a cognitive model similar to COLIDES (Kitajima, Blackmon, & Polson, 2000) that uses latent semantic analysis (LSA) for computing the semantic similarity between link labels and user's goals. Links that had the highest semantic similarity with the goal were selected. When the successful path for a task included a link that was present on the screen, it was highlighted. They found that these highlighted link suggestions were positively received and improved user performance.

But why do we want to give navigational support, limiting free navigation? With navigational support users get information about how ideas between documents are related, or which are the most related links within a set. McNamara and Shapiro (2005) suggest that as novice readers are not able to recognize important relationships between different pages, it is necessary to make novice readers aware of these relationships. MacNamara and Shapiro propose that providing a well-defined domain structure or highlighting the links that denote heavy inter-texts relationships will help less knowledgeable students to comprehend hypertext documents.

One technique to implement navigation support systems was described by Salmerón et al. (2006b) who proposed an automated method for suggesting links based on LSA coherence measures; being on a particular hypertext page the system could signal the links with the highest LSA values regarding the just read text. Such a system could help readers to select a coherent reading order, that is, a reading order that results in a coherent text.

We propose that this system could also support hypertext learners in the reduction of cognitive load in the situations predicted by DeStefano and LeFevre. First, by suggesting some links we try to focus readers' attention on fewer link options, so the cognitive load related with decision making will be lower. Additionally, suggesting semantically related links will lead to a more coherent reading order and therefore, also to a reduction on cognitive load during reading. Therefore, the above mentioned system will also permit a better comprehension and learning.

In this paper, we test hypotheses about the effects of cognitive load on hypertext performance and learning, and the efficacy of navigation support for helping users to overcome navigation problems and to achieve a better learning.

3. Hypotheses

The main purpose of this study, is to analyze the effects of number of links and navigation support on cognitive load and learning. Part of our hypotheses is derived from the predictions of DeStefano and LeFevre (2007). First, making navigational choices in a hypertext will impose more cognitive load when the number of links is higher, either directly – when more links lead to greater requirements for link selection – or indirectly – when more links increase the probability of accessing documents in a semantically unrelated reading order. Second, and as a consequence, higher number of links can impair learning.

The other input for our hypotheses comes from a practical concern: how can we help learners to deal with those problems that DeStefano and LeFevre associated with hypertext use, that is, an increment on cognitive load and unorganized reading? Furthermore, we want to test the usefulness of giving navigation support in the form of link suggestions based on the semantic similarity between the text just read and link labels to solve these problems for learning.
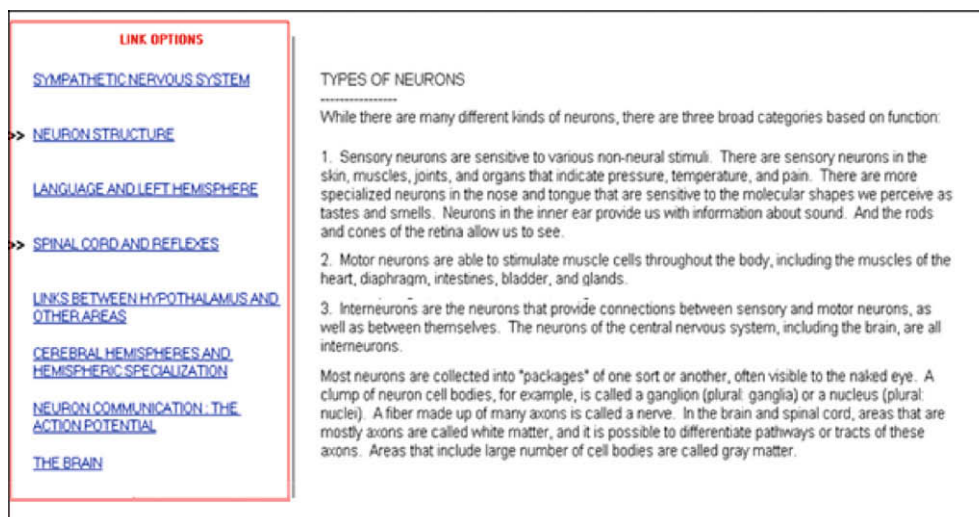

Fig. 1. Screenshot showing the 8-links condition with link suggestions (≫) during link selection.

Therefore, we propose the following set of hypotheses for our research.

3.1. H1: Reading text coherence

Typically, the links shown on a hypertext page lead to a text with different levels of semantic relatedness between successive pages. Showing a high number of links without giving cues about inter-page relations can increase the difficulty to select a coherent navigation path. On the other hand, giving navigation support in the form of link suggestions can help readers to select a coherent reading order. Therefore,

(H1a) Learners using a hypertext with higher <u>number of links</u> will select a less coherent reading order than those using a hypertext with lower number of links.

(H1b) Learners who are given navigation support in the form of <u>link suggestions</u> will select a more coherent reading order than those for whom no support is offered.

3.2. H2: Cognitive load

As we stated before, cognitive load can be affected by the number of links per page in the link selection process as well as during reading. We also propose that link suggestions help readers to reduce cognitive load in the link selection process as well as during reading. Therefore,

(H2a) Learners using a hypertext with a higher <u>number of links</u> will experience an increase in cognitive load during link selection process as well as during reading.

(H2b) Learners who are given navigation support in the form of <u>link suggestions</u> will experience less cognitive load during link selection process as well as during reading.

3.3. H3: Learning

Our hypotheses about learning (Section 3.3) can be deduced as a consequence of our statements about reading text coherence (Section 3.1) and cognitive load (Section 3.2). Hypertext learning will be enhanced when using a system that allows a low cognitive load and a high coherent reading order. Therefore,

(H3a) Learners using a hypertext with a higher <u>number of links</u> will obtain worse learning results than those using less links.

(H3b) Learners who are given navigation support in the form of <u>link suggestions</u> will obtain better learning results than those for whom no support is offered.

4. Method

4.1. Participants

Forty-five students from the Utrecht University participated in the experiment. Since we were interested in testing our hypotheses on low prior knowledge (PK) readers we looked for students who were unfamiliar with the topic of the hypertext (brain anatomy and functioning) by recruiting them in faculties not related with psychology or medicine (most of them were Mathematics, Sociology or Information Sciences students).

The data of three participants was excluded, since they did not follow the instructions properly.

4.2. Design

An experimental 2×2 design was used with number of links (3 vs. 8 links) and support (no support vs. link suggestions) as independent variables. As measures of cognitive load, the dependent variables were the average reaction times (RTs) in a secondary task (separately when reading and when selecting links). Regarding learning outcomes, textbased questions, inference questions and relatedness judgment task scores were used as dependent variables. Mean LSA cosines were used as dependent variable for characterizing participants' reading order. Also, reading and selecting times were used as dependent variables.

4.3. Materials

We used a text about Neuropsychology adapted from a General Psychology introductory e-text (Boeree, 2003). The text had 4.440 words and was adapted into hypertext format. The text was divided into 21 hypertext pages according to their topic structure.

The hypertext was constructed in a specific way to separate the reading processes from the link selection processes. The links selection menu was located on the left of the reading area (see Fig. 1). During reading, the links selection menu was hidden and was only shown when the participants finished reading and they pressed a button with the label "I have finished reading". The links selection menu disappeared again when the chosen link was clicked and the new text was presented on the screen. By this manipulation (separating reading from selecting task) we were able to test independently cognitive load during text reading and during link selection.

Link labels and page titles were constructed using a computational method based on latent semantic analysis (LSA) that allows, for instance, extracting the most representative sentence from a large text (Kintsch, 2002; see Salmerón et al., 2006b for its application to hypertext). LSA has been used as a reliable technique to estimate semantic similarity (e.g. for assessing similarity between short summaries, León, Olmos, Escudero, Cañas, & Salmerón, 2006). By comparing two portions of text with this method one can obtain a measure called LSA cosine that provides a measure of argument overlap (Foltz, Kintsch, & Landauer, 1998). To compute all the LSA measures described in this experiment we used the University of Colorado LSA website, which provides several LSA applications (http://lsa.colorado.edu).

LSA was also used for selecting the link options and link suggestions to be presented at the navigation menu. In both cases, LSA cosines were computed between text contents and the link text labels. On each page, the 2 links with the highest LSA cosines with the text just read were presented, and the rest of the links to complete the menu (until 3 or 8 depending on the condition) was extracted randomly from the pool of links labels. In the support condition the two highest related links were marked with an arrow ($\gg$) near them for making the suggestions (see Fig. 1). The position order of the links in the menu was randomized.

To prevent the participants reading twice the same text, links that lead to an already read text were shown in a different color (like visited links in web pages). Participants could click on these links, but a message was then shown telling them that that content was read before and they had to select a different link.

4.4. Measures

4.4.1. Reading text coherence

Reading text coherence was measured by using LSA to analyze page transitions as determined by the reading order the subjects selected. In our study, the mean LSA cosine between page transitions was computed for every participant as a semantic measure

reflecting the degree of text coherence of the reading order selected by the participants. This measure has been used in previous studies for analyzing reading text coherence in hypertext (Madrid, Salmerón, & Cañas, submitted for publication; Salmerón et al., 2005; Salmerón et al., 2006a).

4.4.2. Cognitive load

For testing our hypothesis on cognitive load we tested participants' mental effort, i.e. the cognitive capacity that was actually allocated to the hypertext task. Mental effort is one of the most important measurable dimensions of cognitive load and in this paper we will use both terms interchangeably. Cognitive load can be measured by a dual-task methodology based on the RTs to probe sounds. This methodology requires participants to perform the main task or primary task while responding to random beeps as quickly as possible (secondary task). Since performance on a task depends on the available cognitive resources, the performance on the secondary task will be reduced if the cognitive resources required by the primary task are high. In other words, the RTs to beeps are slower when the cognitive requirements of the primary task are higher (Bonnardel & Piolat, 2003; Britton & Tesser, 1982; Brünken, Plass, & Leutner, 2003; Kellog, 1987). The results obtained with the dual-task method are interpreted in terms of mental effort applied to the primary task.

In our experiment, at the beginning of the session participants had to react as quickly as possible to 10 beep sounds presented randomly to obtain their RT baseline. During hypertext reading, participants had to press the "z" key as soon as possible when a beep was presented through the headphones. Their data was corrected by subtracting the baseline RTs. Variations in RT's reveal the cognitive capacity allocated to the primary tasks: reading or selecting links. Consequently, we computed the corrected RTs separately when selecting links and when reading the text fragments. The beeps were presented in a variable interval between 15 and 45 s. when reading and between 4 and 9 s. when selecting links. Because the process of making link decisions can be very fast, the time interval during selection was reduced in order to maximize the probability of a beep when selecting a link.

We can compute several measures of cognitive load derived from RTs (see Xie & Salvendy, 2000 for various possibilities). In our analyses, we will use the average cognitive load which reflects the intensity of the cognitive load carried out during the task.

4.4.3. Reading and link selection times

Time spent was measured separately when selecting links and when reading. Link selection times were recorded in seconds, starting when the link menu was shown and finishing when a link label was clicked. An average link selection time was obtained for each participant by dividing the total time spent by the number of link selections in the total session (20 in all the cases). Reading times were measured in seconds for each hypertext page, and then divided by the number of words in that section, obtaining the average time spent by word.

4.4.4. Learning measures

We used different techniques to measure the different representations constructed during reading: textbased questions for textbase representations and inference questions and a relatedness judgment task for the situation model (McNamara et al., 1996; Kintsch, 1998). We also used a questionnaire about prior knowledge for controlling its influence on the development of these representations.

4.4.4.1. Prior knowledge. Although we recruited a low PK sample (at least they were not experts in the topic), we tested them for differences in PK. Prior to the reading phase, participants completed a ten-items questionnaire with questions reflecting general knowledge about the brain, which were extracted from the content of an introductory book on cognitive science (Anderson, 2005). Each question has four choice options, so chance performance was at 25%.

4.4.4.2. Text-based questions. A set of 21 multiple choice questions (one per text page) was also completed by the participants after reading the hypertext. It was constructed in such manner that the question and the answer could be found in the same hypertext page, so there was no need of inferences to respond to it. Chance performance was established at 25%.

4.4.4.3. Inference questions. Ten questions with four response options had to be answered by the participants. This type of questions required to relate information contained in at least two different nodes. Therefore, this task was also intended to assess comprehension at situation model level. Chance performance was at 25%.

4.4.4.4. Relatedness judgment task. The participants had to measure the relation between 91 pairs of concepts (as combination of the 14 most relevant concepts in the text selected by the authors of this paper). Participants had to rate pairs of concepts by using a scale from 1 to 6, in which 1 means "Highly related" and 6 means "Low Related". We applied the Pathfinder Algorithm to the data. Pathfinder is a technique that can provide a measure of the similarity (C) of two conceptual networks that range from 0 to 1 (a score of 1 corresponds to two equal graphs) (see Dearholt & Schvaneveldt, 1990). This method has been shown to be useful to measure comprehension at situation model level (Britton & Gülgöz, 1991). An expert in Psychobiology (Ph.D.) performed this task and his score was used as reference. We calculated the C similarity between each participant's network and the expert network in order to describe how well the situational model has been acquired.

4.5. Procedure

The participants started the session filling in the PK questionnaire. They had then to complete a detection task to determine their reaction time baseline. After that, the hypertext reading phase started, and the participants were instructed to use the hypertext. They had to read all texts. For controlling the effect of different types of strategies on link selection, we instructed the participants to always select the link that seems most related to the just read text. Therefore, participants were instructed to follow a coherence strategy with the intention of promoting text order reading with high coherence (Salmerón et al., 2006a, 2006b).

When reading the hypertext, participants performed a secondary task that consisted of pressing a key when they heard a beep through headphones. The instructions stressed that they had to respond to the sounds as quickly as possible, but that reading and comprehending the text were the main tasks. In the conditions where support was presented, it was explained that the system would show an arrow (≫) near the links that the system assessed as more related with the content just read.

When all text contents were read, participants went to the comprehension testing phase: they started with the relatedness judgment task, continued with the text-based questions and finished with the inference questions. At the end of the experiment participants filled out a questionnaire with demographic data (age, gender, studies, etc.).

5. Results

To control the effect of prior knowledge (PK) on cognitive load and comprehension outcomes, we included the scores on the PK

questions as covariate in all of the further analyses. PK scores could range between 1 and 10. In our study, PK's average was 4.98 with a standard deviation of 2.18.

All results were considered significant when $p < 0.05$, and marginally significant when p values were between 0.05 and 0.10. In this paper, we only present the effects that were significant.

5.1. Reading text coherence

For each participant we computed the mean LSA cosine between text transitions (see Section 4), and this measure was used as dependent variable in the reading text coherence analyses.

A 2×2 (number of links × support) ANCOVA revealed a nearly significant main effect for Number of Links ($F(1,37) = 4.02$; $p = 0.05$) and a significant main effect for Support ($F(1, 37) = 4.84$, $p < 0.05$) on reading text coherence (see Fig. 2). Participants using a hypertext with more links seem to select a less coherent reading order ($M = 0.327$; $SD = 0.053$) than participants using a hypertext with less links ($M = 0.348$; $SD = 0.035$). Also, readers using a hypertext with link suggestions selected a more coherent reading order ($M = 0.351$; $SD = 0.038$) than readers without support ($M = 0.324$; $SD = 0.049$). The interaction was not significant. See Table 1.

5.2. Cognitive load

Our next analyses considered the RTs to probe sounds separately when reading as well as when selecting links. Average cognitive load in link selection ($M = 241.16$; $SD = 58.36$) was higher than during reading ($M = 174.42$; $SD = 90.79$) ($t(41) = -4.007$; $p < 0.01$).

2×2 ANCOVA's using number of links and support as independent variables were performed using average cognitive load for reading and selecting links. No significant effects were found (for all, $F < 1$).

5.3. Reading and link selection times

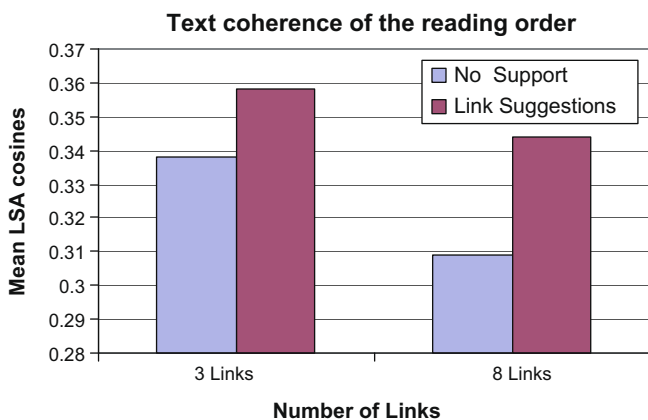2×2 ANCOVA on link selection times shows a main effect of number of links ($F(1,37) = 5.04$; $p < .05$). Participants using a 3-links hypertext need less time to make the selection ($M = 8.80$; $SD = 3.74$) than those using an 8-links hypertext ($M = 12.70$; $SD = 6.68$). There were no significant effects of support neither interaction effects (all F's < 1). Results using mean reading times as dependent variable did not reach statistical significance (all F's < 1).

5.4. Learning results

A set of 2×2 ANCOVAs were conducted on the learning variables. There were no significant effects of number of links or support on scores of the textbased questions scores. On the other hand, a main effect of support on inference questions score was found ($F(1, 37) = 4.63$, $p < 0.05$). Participants' inference questions scores ranged from 1 to 9. Participants using a hypertext with link suggestions learned more at situation model level ($M = 4.52$; $SD = 2.16$) than participants using hypertext without support ($M = 3.33$; $SD = 1.68$) (see Fig. 3). Results on the pathfinder networks' similarity measures did have the same tendency; participants in the support condition tend to show more similar pathfinder networks with the expert's network ($M = 0.261$; $SD = 0.078$ for the no support condition, $M = 0.275$; $SD = 0.119$ for the link suggestions condition), though they did not reach statistical significance ($p > 1$). None of the analyses revealed significant interaction effects ($F < 1$) (see Table 2).

5.5. Discussion

As the results have shown, our hypotheses are only partially supported. First, we found significant results supporting the H1 set of hypotheses: learners using the 8-links hypertext selected a less coherent reading order than those using the 3-links version, and giving navigation support helped learners to select a more coherent reading order.

Second, our hypotheses regarding learning were partially supported. As predicted, learners using the hypertext with link
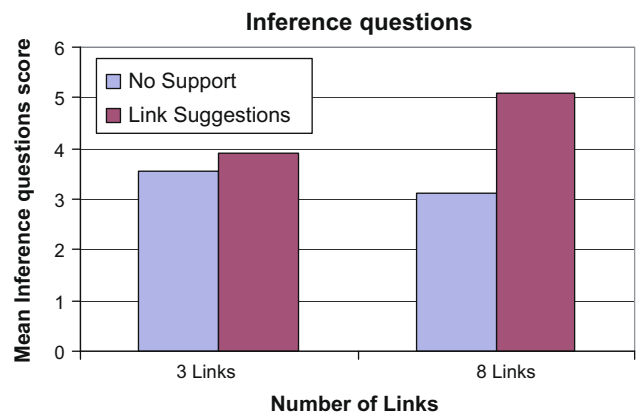
Fig. 2. Effect of number of links and navigation support on the coherence of the reading order.

Fig. 3. Result on inference questions score for number of links and support conditions.

Table 1
Mean LSA cosines (of the reading order) for number of links and support analyses

	3 Links		8 Links	
	No Supp. Mean (SD)	Link Sugg. Mean (SD)	No Supp. Mean (SD)	Link Sugg. Mean (SD)
Mean LSA Cosine	0.338 (0.039)	0.358(0.028)	0.309(0.056)	0.344(0.46)

Table 2
Mean scores on learning measures for number of links and support analyses

	3 Links		8 Links	
	No Supp. Mean (SD)	Link Sugg. Mean (SD)	No Supp. Mean (SD)	Link Sugg. Mean (SD)
Textbased Questions Score	11.09(2.95)	8.70(4.00)	10.30(2.75)	12.18(4.35)
Inference Questions Score	3.55(1.75)	3.90(1.97)	3.10(1.66)	5.09(2.26)
Pathfinder C similarities	0.26(0.09)	0.22(0.06)	0.26(0.06)	0.32(0.14)

suggestions learned more than those using the hypertext without support, at least at situation model level (H3b). On the other hand, we did not find learning impairments for students using a hypertext with more links (H3a).

Finally, none of our hypotheses from the set H2 were supported. Neither varying the number of links nor giving support or not had a significant effect on cognitive load. The fact that more time is needed for selecting when more links are presented can be interpreted as a direct consequence of having to read more link labels prior to make a decision.

One possible explanation for this lack of results regarding cognitive load can be found in the way in which cognitive load and the coherence of the reading order are related. Reading two unrelated text passages imposes more cognitive load than reading two related ones. When two texts are unrelated we need to draw more inferences to comprehend them properly and this consumes more cognitive resources than when texts are related (Kintsch et al., 1999; Masson & Miller, 1983). Consequently, cognitive load can be largely dependent on user actions, and not only on system manipulation. Regardless the effect of number of links and link suggestions in the reading text coherence, readers can still select a low or high coherent reading order in any condition. If some readers are able to select a high coherence reading order even in the conditions without support, the effects on cognitive load could be minimized independently of our manipulations.

We think that reading text coherence can be a strong mediating factor between hypertext design and cognitive load. To analyze this idea, two reading order groups were constructed according to participants' average reading text coherence (the mean of the LSA cosines between traversed nodes). Participants were grouped in a high reading text coherence ($M = 0.371$; $SD = 0.013$) and a low reading text coherence group ($M = 0.304$; $SD = 0.041$), using the median score (Median = 0.353) as the cut-off (see Salmerón et al., 2005 for a similar argument and procedure to group reading orders).

As we can see in Table 3, 1/3 of the readers were not able to select a high text coherence reading order in the conditions with link suggestions, while the same proportion was able to get it in the conditions without support. A similar pattern is found regarding the number of links conditions: 8 participants were able to get a highly coherent reading order in the 8-links condition and also 8 participants selected a low coherent reading order in the 3-links condition. Even in the less favorable condition, 8 links with no support, 20% of the subjects were able to select a high coherent reading order. If there is an effect of reading text coherence on cognitive load, this distribution of participants may have obscured it. It is then possible that we find differences between different levels of reading text coherence influenced by reading order but not necessarily between our manipulated conditions.

To clarify this situation we decided to perform another set of analyses focusing on the text coherence of the reading order as a mediating factor modulating the effect of hypertext design (number of links and link suggestions) on cognitive load and learning. Results are shown and discussed in the next section.

6. The mediating role of reading order on cognitive load and learning with hypertext

A new set of 2 × 2 analyses was performed using number of links and reading order as independent variables (see above). We omit here link suggestions because the cells would become too small. For the 2 × 2 analyses, the 42 participants were distributed as follows: 3-links low text coherence 8 participants; 3-links high text coherence 13 subjects; 8-links low text coherence 13 participants; and 8-links high text coherence 8 subjects.

6.1. Cognitive load

A set of ANCOVA's were performed using number of links and reading order (high or low text coherence) as independent variables. A main effect for reading order ($F(1,37) = 11.65$; $p < 0.01$) was found on average cognitive load during reading (see Fig. 4): participants who selected a more coherent reading order get faster reaction times ($M = 149.14$; $SD = 30.62$) than subjects who had selected a less coherent reading order ($M = 199.70$; $SD = 68.57$). Regarding average cognitive load during link selection, there was a marginally significant main effect of reading order ($F(1,37) = 3.02$; $p = 0.09$). Readers selecting a low coherence reading order seem to have suffered more cognitive load during the link selection process ($M = 261.75$, $SD = 95.67$) than those that selected a high coherence reading order ($M = 220.56$, $SD = 82.79$). No significant main effect for number of links and no interaction effects were found (all F's < 1). See Table 4 for details.

6.2. Reading and link selection times

A set of 2 × 2 ANCOVAs using number of links and reading order (high or low text coherence) was performed on the link selection
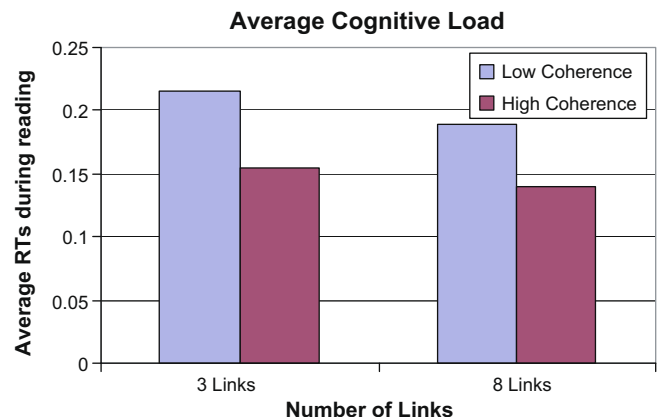

Fig. 4. Average cognitive load during reading.

Table 4
Average cognitive load (RTs in milliseconds) for number of links and reading order

	3 Links		8 Links	
	Low Coh.	High Coh.	Low Coh.	High Coh.
	Mean (SD)	Mean (SD)	Mean(SD)	Mean(SD)
Average cognitive load (Reading)	215.83(88.14)	154.86(31.73)	189.78(55)	139.84(28.17)
Average cognitive load (Link selection)	267.34(96.80)	235.96(78.94)	258.31(98.76)	195.54(88.02)

Table 3
Number of participants performing a high (HC) or low (LC) reading text coherence by condition

	No Support		Link Suggestions		Total	
	LC	HC	LC	HC	LC	HC
3 Links	6	5	2	8	8	13
8 Links	8	2	5	6	13	8
Total	14	7	7	14	21	21

and reading times. Analyses revealed a main effect of number of links on link selection times ($F(1,37) = 6.51$; $p < 0.05$), participants using a 8-links hypertext need more time for selecting the link to follow than those using a 3-links hypertext. There were no significant effects of reading order neither interaction effects (all F's < 1). Analyses on mean reading times showed no significant differences (all F's < 1).

6.3. Learning results

To test directly the effect of text coherence on learning we performed a set of ANCOVAs using reading order and number of links as independent variables. We found a marginally significant effect of reading order on inference questions scores ($F(1,37) = 3.41$; $p = 0.07$), readers selecting a high text coherence reading order performed better ($M = 4.65$; SD = 1.84) on inference questions than readers selecting a low text coherence reading order ($M = 3.27$; SD = 1.96) (see Fig. 5). There was not any effect of number of links or interaction effect. No significant effect was found on pathfinder networks similarities, although it presents the same tendency (higher scores for those selecting a higher text coherence reading order, $M = 0.278$; SD = 0.122 compared with those selecting a lower text coherence reading order, $M = 0.258$; SD = 0.072) as the results on the inference questions. No effect on textbased questions reached significance level (see Table 5).

6.4. Discussion

The results obtained using reading order as independent variable are consistent with those obtained in the previous analyses and add new information. Readers that are able to select a high coherent reading order learned more at situation model level than those who fail in selecting a coherent reading order, independently of the number of links presented in the hypertext.

Regarding cognitive load, there are two significant effects. First, readers selecting a low coherent order suffer more cognitive load

during reading than those selecting a high coherent order. No effect of number of links was found. Thus, the most relevant factor for cognitive load during reading was text coherence.

Second, subjects who were able to select a high coherent reading order also seemed to have suffered less cognitive load during link selection than those subjects who selected a low coherent reading order. Those readers with problems when selecting the most coherent link suffered higher cognitive load. The lack of effect of number of links on cognitive load during links selection can be interpreted by reminding that cognitive load depends on the interaction between task features and user characteristics. Readers can avoid high cognitive load either with 8 or 3 links if they have the needed abilities for a successful navigation. This abilities may include prior knowledge but also experience with computers and hypertext systems, reading abilities, logical reasoning, etc.

Finally, readers selecting a high coherent reading order suffered less cognitive load during reading and obtain a better learning result than those selecting a low coherent one. This finding is experimental evidence for the usefulness of those hypertext designs and navigation support systems directed to enhance the coherence of the reading order, especially for novices.

7. Conclusion

Hypertext design is directed not only to enable information access in an easy way, but also to lead to an optimization of readers' allocation of cognitive resources and to an enhancement in learning. This study was intended to assess the role of some hypertext features based on predictions extracted from Cognitive-Load Theory (Kirschner, 2002; Paas & Merriënboer, 1994; Sweller, 1988) and the Construction - Integration model of text comprehension (Kintsch, 1988, 1998).

This study started with predictions by DeStefano and LeFevre (2007) regarding the effect of number of links on cognitive load and learning. Results did not show any evidence of an increase in cognitive load during link selection when more links were presented nor a reduction in cognitive load when link support was offered. Actually, we found that the increase in cognitive load seems to be directly influenced by the way in which participants read the content. In other words, the coherence realized by the selected reading order mediates the amount of cognitive load that readers experience. Our results also indicate that reading order directly affects learning as well. Participants selecting a high text coherence reading order not only suffered less cognitive load but achieved a better learning at situational level than those selecting a low text coherence reading order.

A possible explanation of the lack of effect of number of links on cognitive load can be the way in which links options were offered. DeStefano and LeFevre predicted effects of the number of links on cognitive load when links where embedded in text, in our experiment however, links where presented in a menu. The reason for this choice is that in this experiment we were also interested in assessing if the effects on cognitive load could be different during reading and during link selection, so links were separated from text. In future experiments, it will be interesting to examine the effects of the number of embedded links on cognitive load.

On the other hand, giving navigation support in the form of link suggestions based on semantic similarity (Salmerón et al., 2006b; Van Oostendorp & Juvina, 2007) helps users in navigation and learning. As predicted, most of the participants selected then a high coherence reading order and subsequently achieved better learning.

Hypertext design and educational implications from this study are related with the role of learner's control in learning with hypertext. Scheiter and Gerjets (2007) have argued that the effectiveness
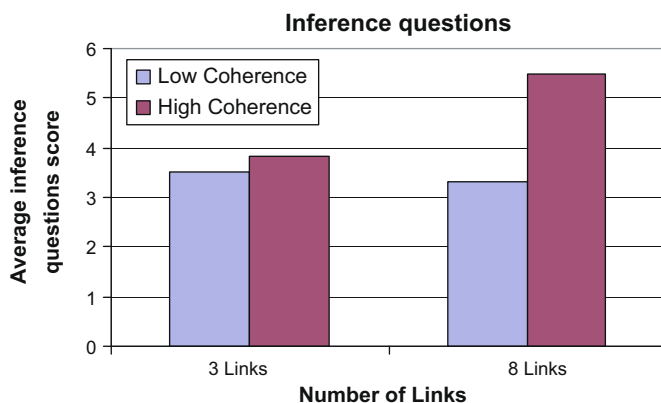

Fig. 5. Mean inference questions score for number of links and reading order.

Table 5
Mean scores on learning measures for number of links and reading order analyses

	3 Links		8 Links	
	Low Coh. Mean (SD)	High Coh. Mean (SD)	Low Coh. Mean(SD)	High Coh. Mean(SD)
Textbased Questions Score	10.12(3.14)	9.85(4.00)	10.15(3.67)	13.125(3.18)
Inference Questions Score	3.50(1.07)	3.85(2.19)	3.31(1.84)	5.50(2.14)
Pathfinder C similarities	0.23(0.06)	0.25(0.09)	0.27(0.07)	0.32(0.16)

of hypermedia depends on how learners make use of this control. In our experiment most participants controlled their learning by means of their navigational choices. However, when using more complex hypertexts or more difficult domain knowledge than the one used in this experiment (i.e. learning about a topic that is completely new and/or very complex) the learner's ability to select the correct reading order probably decreases. In situations like this, the use of hypertext support based on semantic similarity measures such as the one explained in this paper seems to be of big help.

Some limitations of this study are associated with characteristics of both the participants and the materials used in it. The level of prior knowledge or expertise is a reader characteristic that clearly influences learning. Indeed, some studies have demonstrated that techniques that are effective with low knowledge learners can be ineffective or even have negative consequences for learner with higher knowledge level (this is what is known as the expertise reversal effect, see Kalyuga, 2007 for a recent review). We tried to control for prior knowledge by only recruiting students that were unfamiliar with the topic of the materials used in the experiment. However, variations in prior knowledge inside our group of novices were still large, and in several analyses prior knowledge reached statistical significance as covariate. In future research a deeper analysis of the role of prior knowledge and navigational support in hypertext performance seems to be worthwhile.

Acknowledgement

References

Ahuja, J., & Webster, J. (2001). Perceived disorientation: An examination of a new measure to assess Web design effectiveness. *Interacting with Computers, 14*, 15–29.

Amadieu, F., Tricot, A., & Mariné, C. (2006). Prior knowledge and hypertexts structure: A combined effect of a well-organized structure and a coherent pathway on comprehension for novices. *Paper presented at the memory and text comprehension meeting.* Montpellier: 7–8 September.

Anderson, J. R. (2005). *Cognitive psychology and its implications* (6th ed.). New York: Worth Publishers.

Baddeley, A. D., & Hitch, G. (1974). Working memory. In G. H. Bower (Ed.). *The psychology of learning and motivation: Advances in research and theory* (Vol. 8, pp. 47–89). New York: Academic Press.

Baddeley, A. D., & Logie, R. H. (1999). Working memory: The multiple-component model. In A. Miyake & P. Shah (Eds.), *Models of working memory: Mechanisms of active maintenance and executive control* (pp. 28–61). Cambridge, UK: Cambridge University Press.

Boeree, G. (2003). General psychology. Shippensburg University. Available from: http://webspace.ship.edu/cgboer/genpsy.html.

Bonnardel, N., & Piolat, A. (2003). Design activities: How to analyze cognitive effort associated to cognitive treatments? *International Journal of Cognitive Technology, 8*(1), 4–13.

Britton, B., & Gülgöz, S. (1991). Using Kintsch's computational model to improve instructional text: Effects of inference calls on recall and cognitive structures. *Journal of Educational Psychology, 83*, 329–345.

Britton, B., & Tesser, A. (1982). Effects of prior knowledge on use of cognitive capacity in three complex cognitive tasks. *Journal of Verbal Learning and Verbal Behaviour, 21*, 421–436.

Brusilovsky, P. (2004). Adaptive navigation support: From adaptive hypermedia to the adaptive Web and beyond. *Psychology, 2*(1), 7–23.

Brünken, R., Plass, J. L., & Leutner, D. (2003). Direct measurement of cognitive load in multimedia learning. *Educational Psychologist, 38*, 53–61.

Chen, C., & Rada, R. (1996). Interacting with hypertext: A meta-analysis of experimental studies. *Human–Computer Interaction, 11*, 125–156.

Chen, S. Y., Fan, J., & Macredie, R. D. (2006). Navigation in hypermedia learning systems: experts vs novices. *Computers in Human Behavior, 22*(2), 251–266.

Conklin, J. (1987). Hypertext: An introduction and survey. *IEEE Computer, 20*(9), 17–41.

Dearholt, D. W., & Schvaneveldt, R. W. (1990). Properties of pathfinder networks. In R. W. Schvaneveldt (Ed.), *Pathfinder associative networks: Studies in knowledge organization* (pp. 1–30). Norwood, NJ: Ablex.

DeStefano, D., & LeFevre, J-A. (2007). Cognitive load in hypertext reading: A review. *Computers in Human Behavior, 23*(3), 1616–1641.

Dillon, A., & Gabbard, R. (1998). Hypermedia as an educational technology: A review of the quantitative research literature on learner comprehension, control, and style. *Review of Educational Research, 68*, 322–349.

Foltz, P. W., Kintsch, W., & Landauer, T. K. (1998). The measurement of textual coherence with Latent Semantic Analysis. *Discourse Processes, 25*, 285–307.

Graesser, A. C., McNamara, D. S., & Louwerse, M. M. (2003). What do readers need to learn in order to process coherence relations in narrative and expository text. In A. P. Sweet & C. E. Snow (Eds.), *Rethinking reading comprehension.* New York: Guilford Publications.

Jacko, J. A., & Salvendy, G. (1996). Hierarchical menu design: Breadth, depth and task complexity. *Perceptual and Motor Skills, 82*(3), 1187–1201.

Kalyuga, S. (2007). Expertise reversal effect and its implications for learner-tailored instruction. *Educational Psychology Review, 19*(4), 509–539.

Kellog, R. T. (1987). Effects of topic knowledge on the allocation of processing time and cognitive effort to writing processes. *Memory and Cognition, 15*(3), 256–266.

Kim, H., & Hirtle, S. C. (1995). Spatial metaphors and disorientation in hypertext browsing. *Behaviour & Information Technology, 14*, 239–250.

Kintsch, W. (1988). The role of knowledge in discourse comprehension: A construction integration model. *Psychological Review, 95*, 163–182.

Kintsch, W. (1994). Text comprehension, memory and learning. *American Psychologist, 49*(4), 294–303.

Kintsch, W. (1998). *Comprehension: A paradigm for cognition.* New York: Cambridge University Press.

Kintsch, W. (2002). On the notions of theme and topic in psychological process models of text comprehension. In M. Louwerse & W. van Peer (Eds.), *Thematics, interdisciplinary studies* (pp. 157–170). Amsterdam: Benjamins.

Kintsch, W., Patel, V. L., & Ericsson, K. A. (1999). The role of Long-Term Working-Memory in text comprehension. *Psychologica, 42*, 186–198.

Kirschner, P. (2002). Cognitive load theory: Implications of cognitive load theory on the design of learning. *Learning & Instruction, 12*, 1–10.

Kitajima, M., Blackmon, M. H., & Polson, P. G. (2000). A comprehension-based model of Web navigation and its application to Web usability analysis. In S. McDonald, Y. Waern, & G. Cockton (Eds.), *People and computers XIV – Usability or else! proceedings of HCI 2000* (pp. 357–374). London: Springer-Verlag.

Landauer, T. K., & Nachbar, D. W. (1985). Selection from alphabetic and numeric menu trees using a touch screen: Breadth, depth, and width. In *CHI '85 proceedings* (pp. 73–78). New York: ACM Press.

Lawless, K. A., Schrader, P. G., & Mayall, H. J. (2007). Acquisition of information online: Knowledge, navigation and learning outcomes. *Journal of Literacy Research, 39*(3), 289–309.

Lee, M. J., & Tedder, M. C. (2003). The effects of three different computer texts on readers' recall: Based on working memory capacity. *Computers in Human Behavior, 19*, 767–783.

León, J. A., Olmos, R., Escudero, I., Cañas, J. J., & Salmerón, L. (2006). Assessing short summaries with human judgments procedure and Latent Semantic Analysis in narrative and expository texts. *Behavior Research Methods, Instruments and Computers, 38*(4), 616–627.

Louwerse, M. M. (2002). Computational retrieval of themes. In M. M. Louwerse & W. van Peer (Eds.), *Thematics: Interdisciplinary studies* (pp. 189–212). Amsterdam/ Philadelphia: Benjamins.

Louwerse, M. M., & Graesser, A. C. (2004). Coherence in discourse. In P. Strazny (Ed.), *Encyclopedia of linguistics.* Chicago: Fitzroy Dearborn.

Madrid, R.I., Salmerón, L., & Cañas, J.J. (submitted for publication). Cognitive factors and reading strategies involved on comprehension with hypertext systems .

Masson, M. E. J., & Miller, G. A. (1983). Working memory and individual differences in comprehension and memory of text. *Journal of Educational Psychology, 75*, 314–318.

McNamara, D. S., & Kintsch, W. (1996). Learning from texts: Effects of prior knowledge and text coherence. *Discourse Processes, 22*, 247–288.

McNamara, D. S., Kintsch, E., Songer, N. B., & Kintsch, W. (1996). Are good texts always better? Text coherence, background knowledge, and levels of understanding in learning from text. *Cognition and Instruction, 14*, 1–43.

McNamara, D. S., & Shapiro, A. M. (2005). Multimedia and hypermedia solutions for promoting metacognitive engagement, coherence and learning. *Journal of Educational Computing Research, 33*(1), 1–29.

Muller-Kalthoff, T., & Moller, J. (2006). Browsing while reading: Effects of instructional design and learners' prior knowledge. *ALT-J, 14*(2), 183–198.

Paas, F. G. W. C., & Merriënboer, J. J. G. V. (1994). Variability of worked examples and transfer of geometrical problem-solving skills: A cognitive-load approach. *Journal of Educational Psychology, 86*, 122–133.

Parush, A., Shwartz, Y., Shtub, A., & Chandra, M. J. (2005). The impact of visual layout factors on performance in web pages: A cross-language study. *Human Factors, 47*(1), 141–157.

Puerta Melguizo, M. C., Lemmert, V. R., & Van Oostendorp, H. (2006). Lostness, mental models and performance. In V. P. Guerrero Bote (Ed.), *Current research in information sciences and technologies: Multidisciplinary approaches to global information systems* (pp. 256–260). Mérida: Open Institute of Knowledge.

Puerta Melguizo, M. C., Van Oostendorp, H., & Juvina, I. (2007). Predicting and solving web navigation problems. In *Hypertext 2007: Eighteenth ACM conference on hypertext and hypermedia* (pp. 47–48). New York: ACM.

Salmerón, L., Cañas, J. J., Kintsch, W., & Fajardo, I. (2005). Reading strategies and hypertext comprehension. *Discourse Processes, 40*, 171–191.

Salmerón, L., Kintsch, W., & Cañas, J. J. (2006a). Reading strategies and prior knowledge in learning with hypertext. *Memory & Cognition, 34*(5), 1157–1171.

Salmerón, L., Kintsch, W., & Cañas, J. J. (2006b). Coherence or interest as a basis for improving hypertext comprehension. *Information Design Journal, 14*(1), 45–55.

Scheiter, K., & Gerjets, P. (2007). Learner control in hypermedia enviroments. *Educational Psychology Review, 19*(3), 285–307.

Shapiro, A. M., & Niederhauser, D. (2004). Learning from hypertext: research issues and findings. In D. H. Jonassen (Ed.), *Handbook of research on educational communications and technology* (2nd ed., pp. 605–620). Mahwah, NJ: Lawrence Erlbaum Associates.

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science, 12*, 257–285.

Tardieu, H., & Gyselinck, V. (2002). Working memory constraints in the integration and comprehension of information in a multimedia context. In H. Van Oostendorp (Ed.), *Cognition in a digital world*. Mahwah, NJ: Lawrence Erlbaum Associates.

Van Dijk, T. A., & Kintsch, W. (1983). *Strategies of discourse comprehension*. New York: Academic Press.

Van Oostendorp, H., & Juvina, I. (2007). Using a cognitive model to generate web navigation support. *International Journal of Human Computer Studies, 65*, 887–897.

Wenger, M. J., & Payne, D. G. (1996). Comprehension and retention of nonlinear text: Considerations of working memory and material-appropriate processing. *American Journal of Psychology, 109*(1), 93–130.

Xie, B., & Salvendy, G. (2000). Prediction of mental workload in single and multiple task environments. *International Journal of Cognitive Ergonomics, 4*, 213–242.