The Importance of Navigation Support and Reading Order on Hypertext Learning and Cognitive Load

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Abstract: Problems in hypertext learning seem to relate with high levels of cognitive load that learners suffer during hypertext reading. One important factor that can increases cognitive load is the number of links per page (DeStefano & LeFevre, 2007). Several navigation support techniques, such as link suggestions, have been proposed to reduce cognitive load. In an experiment we tested the effects of number of links and link suggestions on cognitive load and learning. Participants used different hypertext versions, 3-links or 8-links per page, and with link suggestions or not. Participants with navigational support selected a more coherent reading text order and learned better at situational level. More interestingly, the effects on cognitive load were mediated by the hypertext reading order. Participants that selected a low coherent reading order suffered more cognitive load independently of the number of links presented. Implications for research and the design of navigation support systems are discussed.

Introduction

Learning with hypertext has become extremely popular in educational settings. The main characteristic of hypertext is that information is presented in a non-linear format allowing learners to navigate and sequence information according to their specific needs and enabling them to develop highly interconnected knowledge structures (Lawless & Brown, 1997). Learning with hypertext however has two problems that limit its usefulness. First, regarding the navigation process and because hypertext documents do not have a tangible structure, they seem to be much more disorienting and confusing to users than linear documents (Conklin, 1987). Second, regarding comprehension and learning there is not conclusive experimental evidence that probes that learners are better with hypertexts than with the traditional books. This is especially true in the case of novices or learners with low prior knowledge on a specific domain. Novices seem to have more difficulties learning from hypertext than experts in the domain (for an extensive review see Chen, Fan & Macredie, 2004). Furthermore, the problems of navigation and learning seem to be related since disorientation leads to worse learning (Puerta Melguizo, Lemmert & van Oostendorp, 2006). Ironically, the flexibility that hypertext offers can be responsible for these problems because, according to DeStefano and LeFevre (2007), hypertext increases considerably user's cognitive load.

Hypertext Comprehension and Cognitive Load

According to the Construction-Integration model proposed by Kintsch (1988), text comprehension is the process of forming coherent mental representations from the text during reading. The two most important mental representations are the textbase and the situation model. 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 (Kintsch, 1994). The most important factors that influence the construction of a situation model are prior knowledge and text coherence. By text coherence we mean the extent to which a reader is able to understand the relations between ideas expressed in a text (Britton & Gulgoz, 1991). When readers with low domain knowledge read a highly coherent text they construct better situation models than when they read low coherent ones (McNamara, Kintsch, Songer, & Kintsch, 1996; Salmerón, Cañas, Kintsch & Fajardo, 2005; Salmerón, Kintsch & Cañas, 2006a).

DeStefano and LeFevre (2007) claim that problems on hypertext can be due to the increase in cognitive load that users suffer because they have to take decisions about what links to follow and consequently, in what order to read and learn from the hypertext. Cognitive load is a multidimensional construct that refers to the load that is imposed to a learner's cognitive system by a certain task. From the general assumption that working memory is a system of limited capacity that can only handle a limited number of elements at the same time, the Cognitive Load Theory claims that optimal learning occurs when the load on working memory is kept between the limits of its capacity (Sweller, 1988; Kirschner, 2002). On the other hand, increasing the cognitive load negatively affects learning and comprehension. Previous studies have indeed found that cognitive load affects hypertext learning. For example, Lee and Tedder (2003) found that readers with high working memory capacity had a better recall of hypertext content compared to those with of low working memory capacity. According to DeStefano and LeFevre (2007), during hypertext reading, users have to decide what link to follow. This decision process requires extra cognitive resources in comparison to linear reading where no decision needs to be made. In relation to this, DeStefano and LeFevre hypothesized that the higher the number of links in a page, the higher is the cognitive load increasing the probability of comprehension problems. Furthermore, when the selected link leads to a semantically unrelated text, the text coherence decreases and the consequence for the reader is an interruption in the comprehension process and learning is impaired. In order to probe this hypothesis, in our experiment we manipulated the number of links presented per page.

Hypertext Navigational Support and Latent Semantic Analysis

In general, low prior knowledge learners are more prone to have difficulties with navigation and comprehension of hypertext (Chen et al., 2004). As a consequence, several navigation support systems have been proposed to assist low prior knowledge learners (McNamara & Shapiro, 2005; Salmerón, Kintsch & Cañas, 2006b). Navigational support has been presented in the form of overviews, concept maps, link suggestions, etc. For example, by providing link suggestions disorientation and cognitive load in hypertext are reduced (Puerta Melguizo, Oostendorp & Juvina, 2007).

Salmerón et al., (2006b) proposed an automated method for suggesting links based on Latent Semantic Analysis (LSA). By comparing two portions of text with this method one can obtain a measure called LSA cosine that provides a measure of the argument overlap or semantic similarity between the texts (Foltz, Kintsch & Landauer, 1998). This measure has been used in previous studies for analyzing text coherence in hypertext (Salmerón et al., 2005). Following Salmerón et al., (2006b), in our experiment we used LSA cosines to suggest links to the readers of a hypertext system. In more detail, in the support condition we selected on every page the two links that had the highest semantic similarity to the content of that page and presented them to the readers as the suggested links to follow.

Experiment

The main purpose of this study was to analyze the effects of number of links and navigational support on cognitive load and learning in hypertext. Part of our hypotheses are derived from the predictions of DeStefano and LeFevre (2007) who stressed the idea that making navigational choices in a hypertext imposes more cognitive load and affects comprehension when the number of links is higher. Furthermore we want to test the usefulness of giving navigation support in the form of link suggestions for comprehension and learning.

We tested several hypotheses. Regarding Cognitive Load, we expect that learners using a hypertext with higher number of links will experience an increase in cognitive load during the processes of link selection and hypertext reading (H1a). Learners with navigation support in the form of link suggestions will however experience less cognitive load during link selection and hypertext reading (H1b). Regarding text coherence, we expect that learners using a hypertext with higher number of links will select a less coherent reading order than those using a hypertext with lower number of links (H2a), and learners who are given navigation support will select a more coherent reading order than those for which no support is offered (H2b). Finally, regarding comprehension and learning with hypertext, we expect that learners using a hypertext with higher number of links will obtain worse comprehension outcomes than those using less links (H3a) and learners who are given navigation support will achieve better comprehension than those for which no support is offered (H3b).

Method

Participants

Forty-five students from Utrecht University participated in the experiment. Since we were interested in testing our hypotheses on low prior knowledge readers we looked for students that were unfamiliar with the topic presented in hypertext: brain anatomy and functioning. With this purpose, we recruited participants in faculties not related with psychology or medicine. The data of three participants were excluded because they did not follow the instructions properly.

Design

An experimental 2x2 design was used with number of links (3 vs. 8 links) and support (no support vs. link suggestions) as independent variables. Several dependent variables were measured:

Prior Knowledge (PK). Although we tried to recruit a low PK sample, we tested participants for differences in PK. Prior to the reading phase, participants completed a questionnaire with 10 questions reflecting general knowledge about the brain. Questions were extracted from an introductory book on cognitive science (Anderson, 2005). Each question had four choice options, so chance performance was at 25 %.

Link Selection and Reading Times. Link selection times were recorded in seconds, starting when the link menu was showed and finishing when a link label was clicked. An average link decision time was obtained for each participant by dividing the total time spent by the number of link selections in the overall session (20 in all the cases). Reading times were measured in seconds for each hypertext page and divided by the number of words in that section, obtaining an average time spent by word.

Cognitive Load (CL) can be measured by a secondary task technique based on the reaction times (RTs) to probe sounds (Brünken, Plass & Leutner, 2003). To obtain participant's RT baseline, at the beginning of the session, they had to react as quickly as possible to 10 beep sounds presented randomly. During the experiment, participants had to press the "z" key as quickly as possible when a beep was presented through the headphones. The data was corrected subtracting the baseline RTs. This measure can be viewed as reflecting the cognitive capacity allocated to the primary task (reading or selecting links). The higher the capacity allocated to the primary task, the longer the reaction times on the secondary task will be. The beeps were presented in a variable interval between 15-45 s. when reading and between 4-9 s. when selecting links. Since link selection can occur very fast, the time interval during selection was reduced to maximize the probability of a beep occurring when selecting. In our analyses, we used the average CL (during selection and during reading) that reflects the intensity of the CL carried during the tasks.

Reading Text Coherence. We computed the mean LSA cosines between text transitions for every participant as a semantic measure reflecting text coherence of the reading order selected by the participant.

Comprehension Outcomes. We used different techniques to measure the different comprehension representations constructed during hypertext reading. For the Textbase representation we constructed a questionnaire with 21 multiple-choice questions (one per text page). The test was constructed in such manner that the question and the answer could be found on the same hypertext page, so there was no need of inferences to respond to it. To assess comprehension at a situation model level, we constructed 10 inference questions with four response options. This type of questions required relating information contained in at least two different nodes. The participants completed both questionnaires after reading the hypertext.

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 divided into 21 hypertext pages. The link selection menu was located on the left of the reading area (see figure 1). To test independently cognitive load during text reading and during link selection, the links selection menu was hidden during reading and was only shown when participants finished reading and pressed a button with the label "I have finished reading". To prevent 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 the content was read before and that they had to select a different link.

Using Latent Semantic Analysis (LSA) link labels and page titles were constructed by selecting the most representative sentence from each page. For the manipulated links options and the link suggestions in the support condition, LSA cosines were calculated between text contents and the link text labels. To select the links options, on each page the 2 links with the highest LSA cosines were presented; the rest of the links to complete the menu (until 3 or 8 depending on the condition) was extracted randomly from the pool of link labels. In the support condition the two highest related links were marked with an arrow (>>) near them for making the suggestions (see Figure 1). The position order of the links in the menu was randomized.

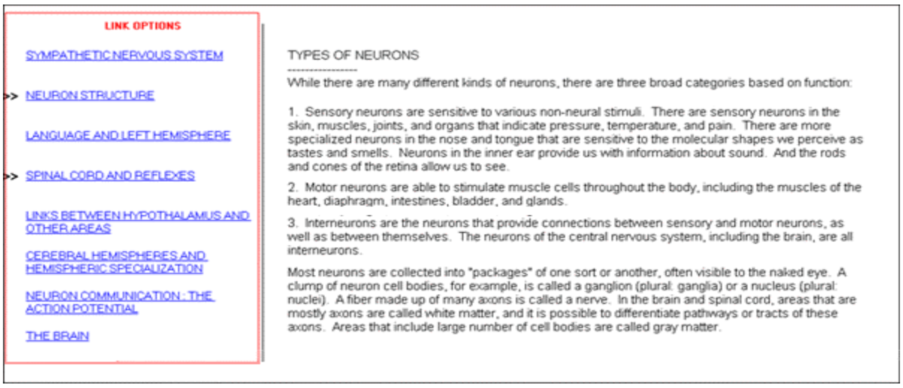

Figure 1. Screenshot showing the 8-links condition with link suggestions during link selection.

Procedure

Participants started the session filling in the prior knowledge questionnaire. Then they completed a detection task to determine their reaction time baseline. After that, the hypertext reading phase started. Participants had to read all hypertext pages and were instructed to select the links that seemed most related to the text just read. Simultaneously with reading, participants performed the secondary task whenever they heard a beep through the headphones. The instructions stressed that they had to respond to the sounds as soon 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 starting with the text-based questions and finishing with the inference questions.

Results

Participants' scores in the Prior Knowledge (PK) test ranged between 1 and 10 with a mean of 4.98 and standard deviation of 2.18. To control the effects of prior knowledge on cognitive load and comprehension outcomes, we included PK as covariate in the analysis. Results with $p<0.05$ were considered significant and marginally significant if p values were between 0.05 and 0.10.

Link Selection and Reading Times

2x2 ANCOVA on link selection times showed 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).

Cognitive Load

We considered the reaction times to probe sounds separately when reading and when selecting links. Average CL in link selection was higher than during reading (M=241.16; SD=58.36 and M=174.42; SD=90.79 respectively) with ($t(41)=-4.01$; $p<.01$). 2x2 ANCOVA's using number of links and support as independent variables were performed using average CL for reading and selecting links. No significant effects were found (for all, F<1; see Table 1).

Table 1: Average CL (RTs in milliseconds) for number of links and support condition (Standard deviation between parentheses).

	3 Links		8 Links	
	No support	Support	No support	Support
Average CL (Reading)	179.22 (54.68)	176.83 (78.14)	177.02 (58.10)	165.06 (48.04)
Average CL (Link selection)	269.30 (81.83)	224.38 (86.74)	233.32 (109.20)	235.38 (91.34)

Reading Text Coherence

To measure reading text coherence, we computed the LSA cosine between text transitions for each participant. A 2x2 (number of links x support) ANCOVA revealed a nearly significant effect of the Number of Links ($F(1,37)=4.02$; $p=0.05$) and a significant effect of Support ($F(1, 37)=4.84$, $p<.05$) on text coherence (see Figure 2). Participants using a hypertext with more links seem to select a less coherent reading order (M=0.33; SD=0.05) than participants using a hypertext with less links (M=0.35; SD=0.04). Also, readers using a hypertext with link suggestions followed a more coherent reading order (M=0.35; SD=0.04) than readers without support (M=0.32; SD=0.05). The interaction between the variables was not significant.

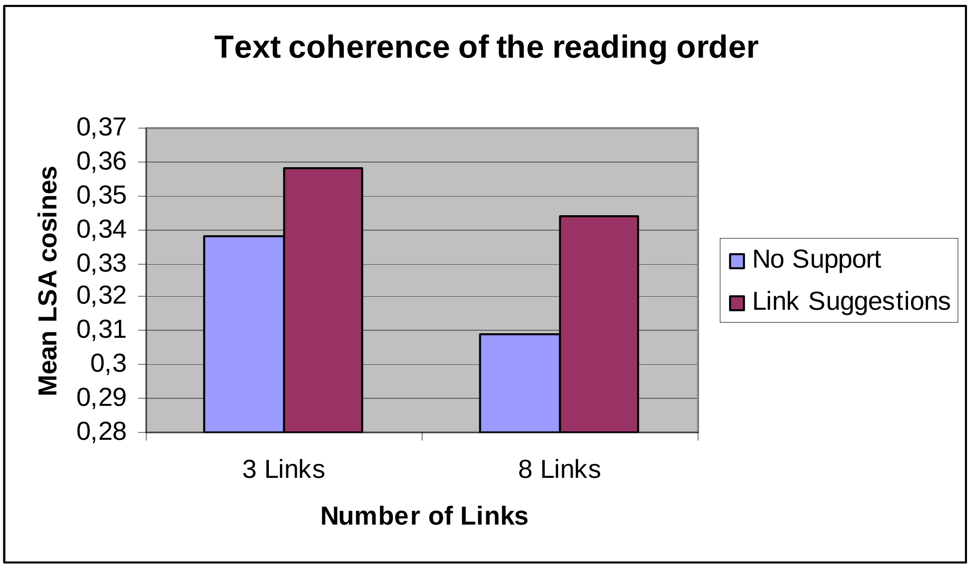

Figure 2. Effect of number of links and navigation support on the coherence of the reading order.

Comprehension

A set of 2x2 ANCOVAs was conducted on the comprehension outcomes. On the textbase questions there were no significant effects of number of links or support. On the other hand, a main effect of support on inference scores was found ($F(1,37)=4.63$, $p<.05$) (See table 2). 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 ($M=3.33$; $SD=1.68$).

Table 2: Average on comprehension measures for number of links and support condition (Standard deviation between parentheses).

	3 Links		8 Links	
	No support	Support	No support	Support
Textbase questions	11.09 (2.95)	8.70 (4.00)	10.30 (2.75)	12.18 (4.35)
Inference questions	3.55 (1.75)	3.90 (1.97)	3.10 (1.66)	5.09 (2.26)

Discussion

Our hypotheses were only partially supported. We found significant results supporting our hypotheses about text coherence. Learners using the 8-links hypertext selected a less coherent reading order than those using the 3-links version (H2a). Furthermore, giving navigation support helped learners to follow a more coherent reading order (H2b). Our hypotheses regarding comprehension were partially supported. As predicted, learners using the hypertext with link suggestions learned more than those using the hypertext without support, at least at a situation model level (H3b), but we did not found learning impairments in those using a hypertext with more links (H3a). Finally, none of our hypotheses regarding cognitive load were supported. Neither the number of links nor giving support had a significant effect on cognitive load (H1a and H1b). The fact that selection times significantly increase when more links are presented can be interpreted as a direct consequence of having to read more link labels in the 8-links condition prior to make the link decision.

The lack of results regarding cognitive load can be due to the influence of the reading order participants selected during the experiment. In our experiment, and regardless of our manipulations, readers could still decide to follow a high (or low) coherent reading order in any condition. For example, if some readers were able to select a high coherent reading order, even in the less favorable condition (i.e. without support and 8-links), then the effects of our variables on cognitive load could have been minimized. To analyze this idea, two reading order groups were distinguished according to participants' average text coherence measured as the mean of the LSA cosines between transited texts. Participants were grouped in a high text reading coherence group ($M=0.37$; $SD=0.01$) and a low text reading coherence group ($M=0.30$; $SD=0.04$), using the median score ($Median=0.35$) as the cut-off (see Salmerón et al., 2005 for a similar procedure to group reading orders). As we see in Table 3, even in the less favorable condition, that is 8-links without support, 20% of the participants were able to select a high coherent reading order. To clarify this situation we reanalyzed the data considering text coherence of the reading order as a mediating factor that modulates the effects of hypertext design on cognitive load. Results are shown and discussed in the next section.

Table 3: Number of participants following a high or low text coherence reading order by condition.

	No Support		Link Suggestions	
	Low Coherence	High Coherence	Low Coherence	High Coherence
3 Links	6	5	2	8
8 Links	8	2	5	6

The Mediating Role of Reading Order on Cognitive Load and Comprehension with Hypertext

A new set of 2x2 ANCOVA analyses was performed using number of links and reading order as independent variables. We omit here link suggestions because the set of data per cell would become too small.

Link Selection Times and Reading Times

The 2x2 ANCOVAs revealed a main effect of number of links on link selection times ($F(1,37)=6.51$; $p<.05$), participants using a 8-links hypertext need more time to select the link to follow than those using a 3-links hypertext. There were no significant effects of the reading order or the interaction between variables (all F's<1). Analyses of mean reading times showed no significant differences (all F's < 1).

Cognitive Load

A main effect of reading order ($F(1,37)=11.65$; $p<.01$) was found on CL during reading. Participants who followed a more coherent reading order had smaller reaction times (M=149.14; SD=30.62) than subjects who followed a less coherent reading order (M=199.70; SD=68.57). Regarding CL during link selection, there was a marginally significant main effect of reading order ($F(1,37)=3.03$; $p=0.09$). Readers following a low coherence reading order suffered more CL during the link selection process (M=261.75, SD=95.67) than those that followed a high coherence reading order (M=220.56, SD=82.79). No significant main effects for number of links and no interaction effects were found (all F's < 1). See Table 4 for details.

Table 4. Average CL (RTs in milliseconds) for number of links and reading order (Standard deviation between parentheses).

	3 Links		8 Links	
	Low Coherence	High Coherence	Low Coherence	High Coherence
Average CL (Reading)	215.83 (88.14)	154.86 (31.73)	189.78 (55)	139.84 (28.17)
Average CL (Link selection)	267.34 (96.80)	235.96 (78.94)	258.31 (98.76)	195.54 (88.02)

Comprehension

No effect on text-base questions reached significance level. We found a marginally significant effect of reading order on inference questions scores ($F(1,37)=3.41$; $p=.07$), readers following a high text coherence reading order performed better (M=4.65; SD=1.84) on inference questions than readers following a low text coherence reading order (M = 3.27; SD = 1.96). There were no significant effects of number of links or interaction. See Table 5.

Table 5: Average on comprehension measures for number of links and reading order (Standard deviation between parentheses).

	3 Links		8 Links	
	Low coherence	High Coherence	Low coherence	High Coherence
Textbase questions	10.12 (3.14)	9.85 (4.00)	10.15 (3.67)	13.12 (3.18)
Inference questions	3.50 (1.07)	3.85 (2.19)	3.31 (1.84)	5.50 (2.14)

Discussion

The results obtained using reading order as independent variable are consistent with those obtained in our previous analyses and, more interestingly, add new information. Readers who were able to select a high coherent reading order learned more at situation level than those who fail in selecting a coherent order, independently of the number of links presented in the hypertext. Also regarding CL, we found that participants who selected a low coherence reading order suffered more CL during selecting links and reading times and that this increase in CL was not related to the number of links.

Conclusions

Although learning with hypertext is nowadays extremely popular, is still not clear whether comprehension and learning is better in comparison to traditional learning methods. One problem related with hypertext is the increase on cognitive load that learners suffer while learning with hypertext. The main reason for the increase on cognitive load is the fact that learners have to decide by themselves what is the best link path to follow (DeStefano & LeFevre, 2007). On the other hand, giving navigation support in the form of link suggestions based on semantic similarity helped users in navigation and learning (Salmerón et al., 2006b; van Oostendorp & Juvina, 2007).

In our experiment we tested the effects of the number of links and link suggestions on cognitive load and learning. As predicted, participants in the support condition followed a high coherent reading order and achieved better comprehension outcomes at a situation model level. In other words, when low prior knowledge learners receive navigation support based on methods that calculate the semantic similarity between connected pages in the hypertext, they are able to develop a more coherent reading order and construct a better situation model of the learned material. In contrast to the predictions of DeStefano and LeFevre (2007), our results did not show any evidence of an increase on cognitive load when more links were presented. We also did not found a reduction on cognitive load when link support was offered. Furthermore, we found that the reading order is a strong mediating factor that directly affects cognitive load. Participants following a high text coherence reading order suffered less cognitive load and achieved a better learning at situational level than those following a low text coherent reading order. As a consequence, we think that hypertext designers should pay more attention to users' reading behavior and strategies when designing navigation tools and mechanisms, since their validity depends on their ability to improve the text coherence of the reading order.

Although we found that participants with navigational support and/or with a high text coherence reading order learned better at situational level, no differences were found for the textbase questions. According to the Construction-Integration model (Kintsch, 1988) the situational representation corresponds to a deeper level of comprehension than the textbase. To construct an adequate situation model implies to construct the correct or coherent connections between the different ideas in the text and the reader's prior knowledge. Consequently, the coherence of the read text influences more the construction of the situational representation than the construction of the textbase representation. McNamara et al., (1996) also found that when readers with low prior knowledge studied high coherence texts learning at situational model was better and no differences appeared with textbase questions. The same results were found on hypertext by Salmeron et al., (2005) and Salmerón et al., (2006a). In order to explain this difference, Kintsch (1994) already made a distinction between text memory and learning from the read text. Learning requires deep understanding on the subject matter whether for memory a more shallow understanding suffices. In our case, the so-called textbase questions mainly demanded participants to recognize ideas presented in the text whereas the inference questions demanded a deeper level of comprehension.

Finally, some limitations of this study are associated with characteristics of both the participants and the materials used in this study. We tried to control for prior knowledge by recruiting only students that were unfamiliar with the topic of the materials used in the experiment. However, variations in prior knowledge 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 in hypertext performance should be carried out.

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