Open Access

Processing Text on the Web: The Construction of Mental Representations

Anja B. Naumann*

Deutsche Telekom Laboratories, TU Berlin, Ernst-Reuter-Platz 7, D-10587 Berlin, Germany

Abstract: Aim of the present study was to identify an appropriate hypertext structure and navigation aids that enhance the comprehensibility of hypertext and support readers in building up a mental representation of the text. It is assumed that hypertext readers construct a content representation for the comprehension of the hypertext and a text structure representation for navigation within the hypertext. If relevant dimensions of these two representations cannot be mapped onto each other, orientation problems are likely to occur. The results of this experimental study show that disadvantages of hypertext concerning orientation problems can be compensated with the aid of a graphical overview which is usable for navigation. This orientation and navigation aid is also an advantage for the speed of information retrieval. However, the coherence of the reading sequence seems to the best predictor for the quality of the mental representations of both text content and hypertext structure. An influence of the availability of cognitive resources was also shown.

INTRODUCTION

Users have to cope with three main tasks when interacting with hypertext: the navigation task, the text comprehension task, and the search task. All three tasks are closely linked with each other. The need for navigation in hypertexts, which does not exist for linear texts, requires cognitive resources [1] and easily leads to disorientation and cognitive overhead. It makes finding of information more complicated and affects text comprehension by preventing the reader from constructing a coherent mental representation of the text content (situation model; see [2]). However, in text comprehension research, building up a coherent mental representation is seen as essential for the comprehension of a text (e.g. [3]).

Hypertext is electronic text which is arranged in a nonlinear order, i.e. the order of text components is only indirectly prearranged by the author of the text. Hypertext is the most common text format on the World Wide Web and, therefore, the basis for most online teaching systems. Text nodes, one of the two components of hypertext – the other being links - are discrete, closed units of information, which must be comprehensible on their own. As the reader can access these text nodes in any sequence, the content of one text node must not be required for the comprehension of any other text node [4]. Global coherence, which gives the entire hypertext its thematic interrelation, has to be established in a much different way compared to traditional linear text and is much more cognitively demanding [1]. Whereas in traditional linear text the author has coherently structured the text, the responsibility for coherent structuring in hypertext is transferred to the reader [5]. An incoherent reading sequence, however, might result in the reader's inability to construct a coherent mental representation of the text content [3, 5].

*Address correspondence to this author at the Deutsche Telekom Laboratories, TU Berlin, Ernst-Reuter-Platz 7, D-10587 Berlin, Germany;
E-mail: anja.naumann@telekom.de

Different linkage principles of text nodes can influence the reading sequence because they determine the navigation options in the hypertext. The permanent update of the mental representation requires cognitive resources. The generation of coherence is complicated because the reader has to solve tasks of information retrieval and weighting in addition to the actual text processing [1]. The decision for a text node to be visited next is lead by the anticipation of the relation of the forthcoming node to the one just read [6]. Readers consciously choose a coherent reading sequence in hypertext [5, 7]. Both the linkage structure and the range of path alternatives influence the construction of a mental representation of the text content: the situation model [2], which integrates the text content and the reader's previous knowledge and is an essential component of text comprehension [8]. Linkage structure and path alternatives have a peculiar influence on the construction of relations (e.g. temporal, causal or spatial) between hypertext nodes. Drawing global inferences in this way is very challenging on the one hand but essential for the comprehension of the text on the other hand [9].

Because of the limited capacity of human working memory [10] it is implausible that hypertext users can match presented information with all the text elements they have already read [1]. Hence, hypertext structure and aids for orientation and structuring in hypertext are rather important in order to facilitate those processes [11]. A well- structured hypertext can reduce the user's cognitive load by enabling him or her to chunk meaningful information [12].

Because the hypertext user has to solve tasks of information retrieval and weighting in addition to the actual text processing [1], he or she has to deal much more intensely with the structure of the hypertext system than the reader of linear text. Therefore, it is assumed that in addition to the situation model also a mental representation of the text structure is constructed [11]. Empirical findings show that hypertext users, in fact, mentally represent the hypertext structure [11, 13, 14], which is supported by the finding that structural aids and navigation tools can enhance performance in hypertext [15, 16].

1875-9343/09

The question is now how to draw conclusions for an optimal hypertext design from the existing research findings regarding hypertext and text comprehension processes. Therefore, the present study investigated the influence of a systematic variation of different hypertext design parameters on the interaction with the hypertext as well as on knowledge acquisition and the construction of mental representations of the text content. We assumed more orientation problems, less acquired knowledge, and an inferior representation of the text content but a better representation of the text structure and a more efficient information search for active navigation than for a predefined reading sequence. For dealing processing coherent text, we assumed less orientation problems, more acquired knowledge, a better mental representation about text structure and text content, and a more efficient information search than for processing incoherent text. With higher working memory load, these results were assumed to be even more clearly.

METHOD

Participants

In this experiment, 128 students of psychology at Chemnitz University of Technology participated for course credits, 101 of them being female and 27 male. On average they were 23 years old (M = 22.56, SD = 3.67). In the first session the participants were asked to read one text (knowledge acquisition) and in the second session their task was searching for specific information (information retrieval) in a second text with different content.

Material

The text material used for the first part of the experiment (knowledge acquisition) was based on an article from a historical magazine about the construction of the Trans-Siberian Railway, which consisted of 3,400 words distributed over 16 text nodes. A trained experimenter analyzed the text structure of this text according to Kintsch [2], using the three basic rules for designing a macrostructure (see [11]). Four chapters with three subchapters each were extracted. In addition, macro- propositions were derived for each chapter (e.g. “reasons for construction of the railway” and “start of construction”), which were then organized into an overview containing text structure information regarding the order of chapters and subchapters in the text. This overview, containing the four main macro- propositions representing the four chapters of the text, was presented in the frame on the left hand side of the screen in addition to the actual text. When participants navigated to one of the four chapters the macro- propositions of the related subchapters were also presented so that participants saw the global text structure and part of the substructure. A yellow background marked the current subchapter.

In order to be able to investigate the effect of non-corresponding text structure and event order, the macro-propositions in one condition were organized in a way that did not follow the chronological order of the historical events (construction phase and problems, end of construction until today, start of construction, and reasons for construction). Thus, the order of chapters in the text structure did not match the order of events in a coherent situation model (incoherent condition: I), whereas in the other condition, the macro- propositions were organized in a chronological, thus coherent, order (coherent condition: C).

We also varied navigation facilities (see Fig. **1**). In the condition “static aid” (S) the text structure overview was presented on the screen but navigation was only possible by using the back- and forward-buttons presented. In the text condition “active aid” (A) the same text and text structure were used, but participants had to navigate by clicking on the different levels in the hierarchy of the text structure. After clicking on one item (chapter) of the text structure the related text was shown in the frame on the right hand side. There were no back- and forward-buttons for navigation in this condition. By combination of these factors four different text conditions were constructed:

A) coherent hypertext with static navigation aid (CS)

B) coherent hypertext with active navigation aid (CA)

C) incoherent hypertext with static navigation aid (IS)

D) incoherent hypertext with active navigation aid (IA).

In addition to this, we varied the cognitive load connected to the task. Working memory load was low in one condition, but increased in the other as the participants had to solve an additional task during the experiment, such as memorizing five-digit numerical orders during reading. When these numerical orders popped up in erratic intervals in an additional window on the screen, participants had to memorize them and then to close the window. After another erratic interval participants were presented with four alternatives in another pop-up window from which they were asked to choose the correct number.

For the second part of the experiment (information retrieval) a second text of the same length and with the same text conditions as in the first part was constructed. Only the content was different from the first text, i.e. concerned with the Crusades.

Apparatus

The experiment was conducted as a browser- based experiment. The texts were electronically presented on a 21” monitor of an IBM compatible computer. They were displayed with Microsoft Internet Explorer Version 4.0. While participants were reading the text, logfile protocols of all navigation operations were recorded. These logfiles were evaluated by using the Chemnitz LogAnalyser 2.13, which is a tool for analyzing data from web- based experiments [17]. The logfiles contained the performance in the secondary task, the order of pages visited, and the time spent on each page.

Design

The study was conducted as a between-subject design with four text conditions (see material). The design was a 2x2x2 design with the factors coherence of text structure (coherent *vs* incoherent), navigation (static *vs* active) and working memory load (low *vs* high). Participants were randomly assigned to one of these conditions. The dependent variables included reproduction of the text structure, reproduction of the text content (readers’ situation model), navigation behavior as well as problems of orientation.

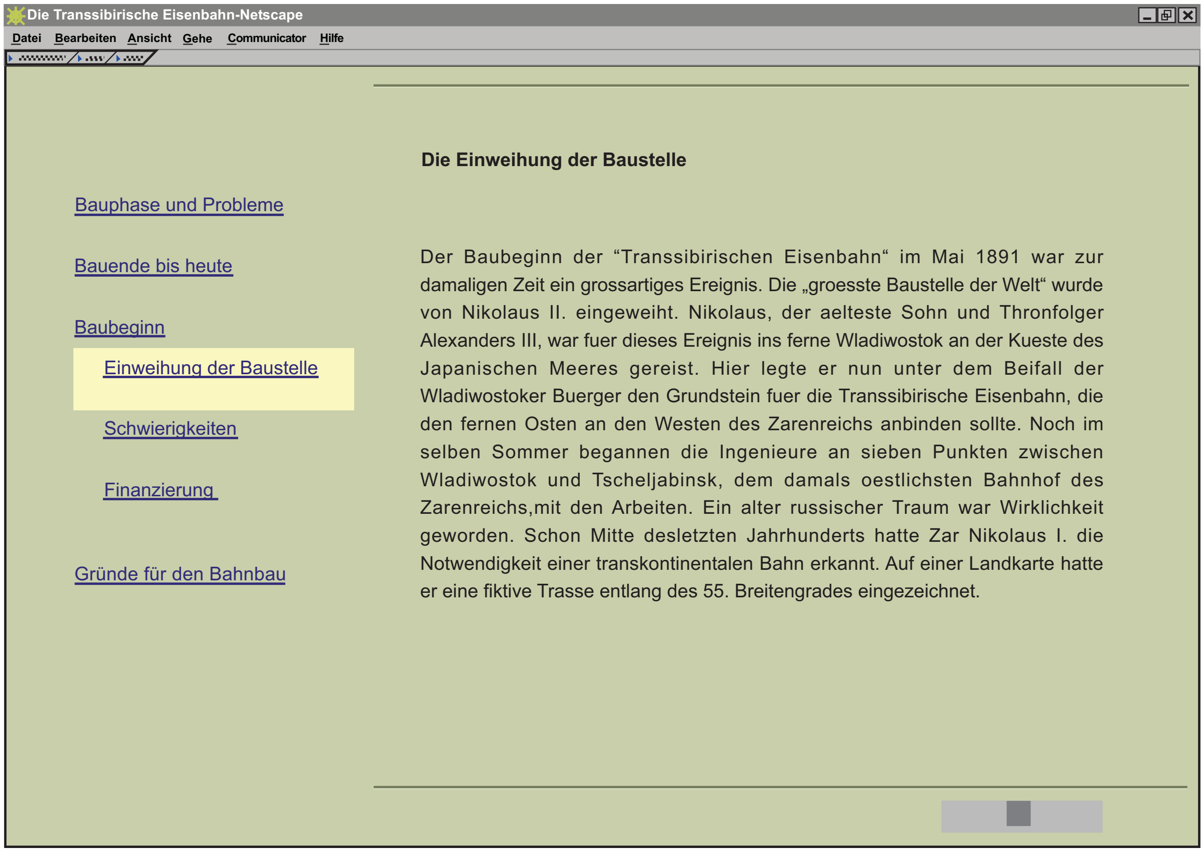

Fig. (1). Example page for the condition with static navigation aid (top) and active navigation aid (below).

Procedure

In the first session, participants had to read the text about the Trans-Siberian Railway carefully. In the second session, they had to answer 15 search questions with the help of the text about the Crusades. Participants were tested individually. First they had to fill in a questionnaire concerning their attitudes towards and their experience with computers followed by a test of their prior knowledge about the text content domain (Trans-Siberian Railway/Crusades). Then, the actual reading/searching task followed. Taking notes was not allowed. After finishing the reading/searching task participants were asked to write a short summary (for assessing the situation model) of the text and answer multiple choice questions concerning specific text information. The last questionnaire was concerned with problems of orientation experienced while reading the text. Finally, participants had to complete a card sorting task in order to assess the mental representation of the text structure.

RESULTS

Knowledge Acquisition

Navigation Behavior and Orientation Problems

Participants who read the text with the active navigation aid (N = 64) exploited this high degree of freedom quite differently. They either read the text in a passive way from the beginning to the end or they assorted the sequence of text nodes actively, in most cases attempting to bring them in a coherent order in the incoherent condition. Here, more navigation steps (M = 28.05, SD = 12.62) were needed than in the coherent condition (M = 23.84, SD = 8.78), $F(1, 119) = 5.09, p = .026$.

As we assumed, participants reported more problems for learning the incoherent text (M = 2.51, SD = 0.57) than for learning the coherent text (M = 2.23, SD = 0.53), $F(1, 120) = 5.05$; $p = .026$, part. Eta^2 = .04. Also in line with our assumptions, for reading with higher working memory load (M = 1.79, SD = 0.48), participants reported more orientation problems than for reading with low working memory load, M = 1.59, SD = 0.36, $F(1, 120) = 6.69$; $p = .011$, part. Eta^2 = .05. Contrary to our assumptions, participants reported more orientation problems for the "static aid" (M = 1.77, SD = 0.46) than for the "active aid" condition, M = 1.61, SD = 0.39, $F(2, 119) = 3.48$; $p = .034$, part. Eta^2 = .06. A more detailed analysis showed that the reason for that is that participants in the "static aid" condition had more problems in getting an overview of which information was related to which text node just because there was no need to explore the text structure.

Mental Representation of the Text Structure

For measuring the text structure representation, the accordance of the structure in the card sorting task with the original text structure was calculated (Kendalls τ). As the results show, the coherence of text structure has an important influence on this correlation: Participants reading the incoherent text were not at all able to reprocuce the original text structure (Mdn = -.10, P_{25} = -.29, P_{75} = .30) whereas participants reading the coherent text were quite able to do so, Mdn = .75, P_{25} = .54, P_{75} = .88; $H(1) = 60.21$; $p < .01$. For the high cognitive load conditions, this result was most obvious. The navigation aid had no influence on the text structure representation. Because participants reading the incoherent text were not able to represent the original text structure, we assumed that they probably represent the text structure in a coherent way according to the situation model. And in fact, the correlation of the laid structure with the structure according to the situation model (Mdn = .20, P_{25} = -.11, P_{75} = .46) was much higher than the correlation with the original incoherent text structure (Mdn = -.10, P_{25} = -.29, P_{75} = .30). This shows the surprising result that readers restructure the incoherent text in their mental representation in order to get a chronological and coherent representation of the text.

Factual Knowledge

As we assumed, in the coherent static condition (CS) with low cognitive load, most correct facts were stated for the open questions in the knowledge test (M = 4.06, SD = 1.34) and least in the incoherent static condition (IS) with high cognitive load, M = 2.63, SD = 1.09, $F(1, 116) = 4.00$; $p = .048$, part. Eta^2 = .03. The same interaction was shown for the facts in the summaries written by the participants. For all knowledge tests, a negative correlation of orientation problems and factual knowledge was shown: multiple choice (Spearman Rho: -.29, $p = .001$), open questions (-.23, $p = .010$), facts in the summaries (-.24, $p = .007$). This means that according to our assumptions, participants reporting more orientation problems acquired less factual knowledge.

Mental Representation of the Text Content

Both navigation aid and cognitive load had a significant influence on the identification of true sentences not belonging to the original text: According to our assumptions, participants in the static condition (M = 3.56, SD = 1.00) identified more sentences correctly as not belonging to the text than participants in the active condition, M = 3.05, SD = 1.09, $F(1, 116) = 8.70$; $p = .004$, part. Eta^2 = .07. And, participants in the condition with low working memory load (M = 3.60, SD = 1.08) identified more sentences correctly than participants in the condition with high working memory load, M = 3.02, SD = 1.00, $F(1, 116) = 10.41$; $p = .002$, part. Eta^2 = .08. The coherence of text structure had no influence on sentence recognition. This leads to the assumption that participants reading the incoherent text were indeed able to build up a mental representation close to the text but that does not necessarily mean that they were also able to build up a chronologically coherent situation model about the text content.

For measuring the temporal coherence of the text content representation, the sequence of facts reproduced by the participants in the text summaries was correlated with the sequence of these facts according to a chronological situation model (Kendalls τ). In general, the participants were quite able to build up a coherent representation about the text content (τ = .69, P_{25} = .44, P_{75} = .83). Only the coherence of text structure had a significant influence on the quality of the mental representations $H(1, 126) = 3.95$; $p < .05$). As we assumed, participants reading a coherent text were much more able to build up a coherent situation model about the text content than participants reading text structured in a non coherent sequence. Especially in the condition with high cognitive load was shown that this situation model was most coherent in the CS condition (Mdn = .80, P_{25} = .56, P_{75} = .90) and least coherent in the IS condition (τ = .68, P_{25} = .06, P_{75} = .81), which supports the results for factual knowledge.

Information Retrieval

Navigation Behavior, Orientation Problems, and Efficiency of Search

Participants had to answer 15 search questions with the help of the text about the crusades. They needed nine steps on average in order to answer one search question ($M = 9.39$, $SD = 2.99$; *Min.*: 3.93, *Max.*: 24.93). There was a significant interaction of navigation aid and coherence of the text structure, $F(1, 116) = 13.22$, $p = .000$. Participants in the incoherent static-aid condition (IS) needed the highest number of navigation steps ($M = 187.10$, $SD = 26.65$) whereas participants in the coherent active-aid condition (CA) needed the least ($M = 112.47$, $SD = 22.26$). Participants who needed more navigation steps also reported more orientation problems (ρ = .25, $p = .006$, $N = 118$). The analysis of navigation behavior emphasizes the results for knowledge acquisition: In the incoherent text condition 28% of the participants with the static aid (IS) and 22% of the participants with the active aid (IA) tried to read the text in a coherent sequence, even though the text structure suggested an incoherent reading sequence. Participants conducting a secondary task mostly tended to follow the reading sequence suggested by the system. Probably they did not have enough cognitive resources in order to restructure the text into a coherent sequence.

As for knowledge acquisition, also for information retrieval there is a significant negative correlation between factual knowledge and orientation problems. Participants who reported more orientation problems answered less open questions correctly ($r_s = -.20$; $p = .028$, $N = 125$) and mentioned less correct facts in the text summaries ($r_s = -.23$; $p = .011$, $N = 122$).

As we assumed, participants searching for information with the help of the text with static navigation aid needed significantly more time for their search ($M = 1915.8$s, $SD = 340.9$) than participants searching with active navigation aid, $M = 1691.4$s, $SD = 456.8$, $F(1, 118) = 10.34$, $p = .002$, part. $Eta^2 = .08$. The reason for that is that they had to go trough the text in a linear sequence until they had found the information they were looking for. On answering the search questions, only the coherence of text structure had a significant influence, $F(1, 117) = 8.37$, $p = .005$, part. $Eta^2 = .07$: Participants searching for information in the coherent text answered significantly more search questions correctly ($M = 12.68$, $SD = 1.71$) than participants searching the incoherent text ($M = 11.8$, $SD = 1.88$). In addition, a significant interaction between coherence and navigation aid was shown, $F(1, 117) = 20.22$, $p = .000$, part. $Eta^2 = .15$: The number of correct answers was the highest for the CS condition and the lowest for the IS condition. This is in line with the results for knowledge acquisition in the first part of the experiment.

Mental Representation of the Text Structure

As a result of the task, after searching information in the text, participants were not as much able to reproduce the original text structure as they were after reading the text. However, participants searching for information in the coherent text were still able to reproduce the original text structure in the card sorting task (*Mdn* = .47, P_{25} = .34, P_{75} = .62). In contrast, participants working with the incoherent text, were not at all able to represent the original text structure, *Mdn* = -.03, P_{25} = -.21, P_{75} = .26, $H(1, 121) = 54.19$; $p < .01$. Contrary to the knowledge acquisition task, participants working with the incoherent text did not build up a coherent text representation. The correlation of the laid structure with the coherent situation model (*Mdn* = .03, P_{25} = -.08, P_{75} = .13) was not higher than the correlation with the original text structure. This result shows that participants searching for information in the incoherent text were not able to build up any representation about the text.

Mental Representation of the Text Content

In general, the mental representations about the text content were not much in accordance with the coherent situation model (τ = .09, P_{25} = -.86, P_{75} = 1.00). Only the participants searching the coherent text were significantly better in building up a coherent situation model (*Mdn* = .25, P_{25} = -.16, P_{75} = .62) than the participants searching the incoherent text, *Mdn* = .00, P_{25} = -.34, P_{75} = .22, $H(1, 121) = 10.02$; $p < .01$. Also, participants in the low cognitive load condition (*Mdn* = .17, P_{25} = -.26, P_{75} = .49) were a little better than participants with high cognitive load, *Mdn* = .00, P_{25} = -.29, P_{75} = .28, $H(1, 121) = 2.89$; $p < .10$. In addition, there was a significant negative correlation between reported navigation and orientation problems and the accordance of facts in the summaries with the situation model, $r_s = -.22$; $p = .014$, $N = 121$: Participants who reported less orientation problems were according to this more able to construct a coherent mental representation about the text content than participants who experienced more orientation problems.

DISCUSSION

The results show that disadvantages of hypertext concerning orientation problems can be compensated with the aid of a graphical overview which is usable for navigation. This orientation and navigation aid is also an advantage for the speed of information retrieval. We were able to show that readers construct a mental representation of both the text content (situation model) and the text structure. This is in line with earlier findings [5]. Coherence of text structure was the best predictor for the quality of the constructed mental representations. Only if hypertext is constructed in a way that a coherent reading sequence is suggested to the reader, the user is able to construct a coherent mental representation about the text content. This is in line with earlier findings (e.g. [18, 19]). Interestingly, participants reading the text in an incoherent sequence seem to reconstruct the hypertext structure mentally and represent it according to their situation model. Our data suggest that readers prefer a coherent reading sequence of historical events in hypertext, which supports results from earlier studies [7, 5]. Readers even consciously and actively search for a coherent reading sequence, which is only possible if enough cognitive resources are available. The static navigation aid supports dealing with coherent text but is at a disadvantage for incoherent text which has to be restructured. The hypothesis, that active navigation aid should result in more elaborated mental representations than a static navigation aid, can not be supported.

To summarize, the data suggest that the construction of the reader's coherent situation model from the hypertext read works best for coherently structured text. If hypertext systems do not meet the users' expectations or the readers' situation models, it is difficult for users to construct a mental representation of the hypertext system, especially when cognitive resources are limited. This should be even more evident for more complex hypertext systems than the ones used in this study. It also becomes apparent that different tasks, in this case reading a text *vs* information retrieval, make different demands to hypertext. To some extend, the results were only shown with high working memory load, which shows the influence of the availability of cognitive resources [1].

ACKNOWLEDGEMENTS

I would like to thank the German Science Council DFG, which provided support for this research. In addition, I would like to thank Prof. Dr. Josef F. Krems and Dr. Jaqueline Waniek from Chemnitz University of Technology for their help.

REFERENCES

[1] Ohler P, Nieding G. Kognitive Modellierung der Textverarbeitung und der Informationssuche im World Wide Web [Cognitive modeling of text comprehension and information retrieval on the World Wide Web]. In: Batinic B, Ed. Internet für Psychologen. Göttingen: Hogrefe 2000; pp. 219-40.

[2] Kintsch W. Comprehension: a paradigm for cognition. New York: Cambridge University Press 1998.

[3] Graesser AC, Millis KK, Zwaan RA. Discourse comprehension. Annu Rev Psychol 1997; 48: 163-89.

[4] Bogaschewsky R. Hypertext/Hypermedia-Systeme – Ein Überblick [Hypertext/Hypermedia-Systems – An overview]. Informatik-Spektrum 1992; 15: 127-43.

[5] Waniek J, Brunstein A, Naumann A, Krems JF. Interaction of text structure representation and situation model in hypertext reading. Swiss J Psychol 2003; 62: 103-11.

[6] Storrer A. Was ist "hyper" am Hypertext? [What is "hyper" with hypertext?]. In: Kallmeyer, W, Ed. Sprache und Neue Medien. Berlin: Walter de Gruyter 2000; pp. 222-49.

[7] Foltz PW. Comprehension, coherence, and strategies in hypertext and linear text. In: Rouet, JF, Levonen, JJ, Eds. Hypertext and cognition. Hillsdale NJ: Lawrence Erlbaum Associates 1996; pp. 109-36.

[8] Zwaan RA, Radvansky GA. Situation models in language comprehension and memory. Psychol Bull 1998; 123(2): 162-85.

[9] Graesser AC, Singer M, Trabasso T. Constructing inferences during narrative text comprehension. Psychol Rev 1994; 101(3): 371-95.

[10] Baddeley A. Working memory. Science 1992; 255: 256-9.

[11] Waniek J. Globale Kohärenz in Hypertexten: Experimentelle Untersuchungen zum Generieren von kausalen und zeitlichen Inferenzen [Global coherence in hypertext: Experimental studies of the generation of causal and temporal inferences]. Dissertation 2002, available from http://archiv.tu-chemnitz.de/pub/2003/0090

[12] Salmeron L, Canas JJ, Fajardo I, Gea M. Effects of perceptual and semantic grouping on the acquisition of hypertext conceptual models. In: Harris, D, Duffy, V, Smith, M, Stephanidis, C, Eds. Human-Centred Computing: Cognitive, Social and Ergonomic Aspects, Volume 3 of the Proceedings of HCI International 2003. Mahwah, New Jersey: Lawrence Erlbaum; 2003; pp. 562-6.

[13] Otter M, Johnson H. Lost in hyperspace: Metrics and mental models. Interact Comput 2000; 13(1): 1-40.

[14] Naumann A. Wissenserwerb und Informationssuche mit Hypertexten: Die Bedeutung von Strukturierung, Navigationshilfen und Arbeitsgedächtnisbelastung [Knowledge acquisition and information retrieval with hypertext: The impact of structure navigation aids and working memory load]. Dissertation 2003, available from http://archiv.tu-chemnitz.de/pub/2004/0117

[15] Chen C, Rada R. Interacting with hypertext: a metaanalysis of experimental studies. Hum Comput Interact 1996; 11: 125-56.

[16] McDonald S, Stevenson RJ. Effects of text structure and prior knowledge of the learner on navigation in hypertext. Human Factors 1998; 40(1): 18-27.

[17] Brunstein A, Naumann A, Krems JF. The chemnitz loganalyzer: a tool for analyzing data from hypertext navigation research. Behav Res Methods 2005; 37: 232-9.

[18] Foltz PW, Kintsch W, Landauer TK. The measurement of textual coherence with latent semantic analysis. Discourse Process 1998; 25(2-3): 285-307.

[19] McNamara DS, Kintsch E, Songer NB, Kintsch W. Are good texts always better? Interactions of text coherence, background knowledge, and levels of understanding in learning from text. Cogn Instr 1996; 14(1): 1-43.

Received: January 1, 2008 Revised: September 1, 2008 Accepted: November 1, 2008