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Prior knowledge in learning from a non-linear electronic document: Disorientation and coherence of the reading sequences

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ABSTRACT

A study was carried out to investigate the effects of prior knowledge on learning with a non-linear electronic document including an interactive conceptual map. Cognitive Load Theory was used as theoretical framework to investigate effects on cognitive load and disorientation in learning from non-linear documents. Forty-four future high school biology teachers were required to learn the multiplication cycle of a virus from either a hierarchical structure (organisational links) or a network structure (relational links). For the low prior knowledge learners, the results showed that the hierarchical structure supported better free recall performance and reduced feelings of disorientation. In contrast, the high prior knowledge learners performed better and followed more coherent reading sequences in the network structure. However, no interaction effect between prior knowledge and the type of structure was observed on mental effort and disorientation ratings. The results and the construct of disorientation are discussed in light of the processing demands in non-linear documents.

1. Introduction

A hypertext may be defined as "a requiring system which demands the user finds his/her path in a complex information space" (Dillon, Mc Knight, & Richardson, 1993, p.169). Hypertexts can be used as instructional systems allowing learners to explore information according to their learning needs and individual characteristics. Despite their potential to adapt to the learner's needs, hypertexts are not always as effective for learning as expected (Amadieu & Tricot, 2006; Dillon & Gabbard, 1998). In comparison with a classic linear text, a hypertext requires learners to establish their own reading sequence through the hypertext and integrate information from different locations (e.g., establishing semantic relations between information nodes). A hypertext also demands that learners determine whether information should be found to fill in possible information gaps, and decide where they have to look for that information (Shapiro & Niederhauser, 2004). Therefore, navigating in a hypertext can lead to disorientation, caused by the difficulty users encounter in keeping track of their position in the network and determining how to reach another location in the network (Conklin, 1987). Disorientation thereby adds to cognitive load, that is, it requires extra working memory resources (e.g., Wright, 1991). When this interferes with learning, it is called extraneous cognitive load (Sweller, van Merriënboer, & Paas, 1998).

Two main factors may affect this additional processing demand: (a) the type of hypertext structure that guides the reading path and thereby may help processing the non-linear text, and (b) prior domain knowledge which supplies cognitive resources that either enable orientation or at least make disorientation less harmful. Understanding the way these factors influence individuals' learning in this medium has important implications for designing effective hypertexts as well as implications for modelling learning from hypertexts. From this perspective, the aim of the study was to investigate the effects of hypertext structure and learners' prior domain knowledge on cognitive load, disorientation, navigation and learning performance in non-linear documents. The study intends to uncover how these factors influence the cognitive requirements of learning from hypertexts and how they support effective processing and learning.

The following section argues why Cognitive Load Theory (CLT, Sweller, 2003) provides a relevant theoretical framework to study learning from hypertexts and discusses cognitive load and disorientation constructs. The second section presents the main empirical results of the study, in particular the interaction effects between prior knowledge and hypertext structures.

1.1. Cognitive Load Theory: a framework to study learning from non-linear documents cognitive requirements of hypertexts

Different theories and models have been used in hypertext research literature for 20 years: constructivist approaches (Jonassen, 1989; Jonassen & Wang, 1993), cognitive flexibility theory (Jacob-

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son, Maouri, Mishra, & Kolar, 1996; Mishra & Yadav, 2006; Spiro, Feltovich, Jacobson, & Coulson, 1991), text comprehension models (Potelle & Rouet, 2003; Rouet, Britt, Mason, & Perfetti, 1996; Salmeron, Cañas, Kintsch, & Fajardo, 2005; Shapiro & Niederhauser, 2004), and schema theory (Gall & Hannafin, 1994; McDonald & Stevenson, 1998a). Recently, authors have also applied CLT to interpret the use of hypertexts for learning (Amadieu & Tricot, 2006; DeStefano & LeFevre, 2005; Gerjets & Scheiter, 2003; Gerjets, Scheiter, Opfermann, Hesse, & Eysink, in this issue; Schnotz & Heiß, in this issue).

CLT investigates instructional effects, taking knowledge about the human cognitive architecture as a starting point. Many studies in CLT have focused on the interface between the cognitive requirements of a learning task and the learners' resources such as task expertise. The cognitive load construct occupies an important place in the theory explaining the relationship between an instructional design and the learning outcomes. The theory distinguishes three types of cognitive load imposed by a learning task (Sweller et al., 1998): (a) intrinsic cognitive load (related to the number of information elements and the level of element interactivity inherent in the task), (b) extraneous cognitive load (the load created by the instructional design that does not contribute to learning), and (c) germane cognitive load (the load spent directly on learning). To be most effective, an instructional design has to reduce extraneous cognitive load and promote germane cognitive load (see Paas, Renkl, & Sweller, 2003; Sweller et al., 1998).

From research into hypertext environments, many authors claim that hypertexts may cause high cognitive load or disorientation (e.g. Conklin, 1987; Foltz, 1996; McDonald & Stevenson, 1998b; Mohageg, 1992; Niederhauser, Reynolds, Salmen, & Skolmoski, 2000; Wright, 1991). Navigating across non-linear environments is an activity which can interfere with the learning task because it requires additional resources in working memory (WM). According to DeStefano and LeFevre (2005), reading hypertexts would require important processing in WM like making decisions on the next information to process. Additionally, hypertext users have to plan their reading paths and construct a representation of the hypertext structure to navigate across the information space. In fact, processing non-linear information requires more relational processing than item specific processing (Wenger & Payne, 1996). Thus to understand the information conveyed by a hypertext, learners have to establish semantic relations between the nodes and to construct a representation of the semantic hypertext structure. A high number of embedded links and a large semantic distance between information nodes would provoke high cognitive load (DeStefano & LeFevre, 2005). Consequently, in many circumstances, navigating or reading is highly demanding for a learner, causing high extraneous cognitive load as it not directly concerned with learning, and hampering the learning processes. Thus, to increase the effectiveness of hypertext, navigation should be less demanding.

1.2. Cognitive load and disorientation

According to CLT, cognitive load depends on the interaction between task features and learners' features (Paas & van Merriënboer, 1994) and can be measured by assessment of mental effort and learning performance (Paas, 1992). Mental effort corresponds to the cognitive capacity allocated to completing the task demands and reflects a global cognitive load (i.e. encompassing the three forms of cognitive load).

Disorientation is a psychological state resulting from problems in constructing the pathway across a hypertext. Disorientation may be *structural* (related to the physical space of hypertexts) or *conceptual* (related to the conceptual space of hypertexts; Cress & Knabel, 2003). *Structural disorientation* refers to Conklin's definition of disorientation (Conklin, 1987), reflecting a cognitive load linked to the processing of physical space (e.g., location of the position in the physical space, representation of the previous path). C*onceptual disorientation* concerns the users' difficulties to meaningfully link the different concepts conveyed by a hypertext.

From a CLT perspective, structural and conceptual disorientation may be considered an extraneous cognitive load because it is the consequence of ineffective processes during learning. Therefore studying cognitive load engaged in processing of non-linear information should consider two measures: (a) mental effort which allows the assessment of global cognitive load and (b) structural and conceptual disorientation, which allows an assessment of extraneous cognitive load.

In the field of hypertext research, only a few studies have measured cognitive load (e.g., Wenger & Payne, 1996; Zumbach & Mohraz, ~~in press~~) or disorientation (Ahuja & Webster, 2001; Otter & Johnson, 2000). With respect to disorientation, a number of different measures have been used (e.g., subjective rating scales, verbal reports, navigational behavior, outcome performance), making it difficult to draw consistent conclusions. Hence the relationship between cognitive load and disorientation in hypertext learning needs further investigation.

1.3. Effects of hypertext structures and prior knowledge

To reduce cognitive load and disorientation, learners need to be guided in both the construction of a reading path across a hypertext (i.e., reducing structural disorientation) as well as in the construction a coherent mental model for it (i.e., reducing conceptual disorientation). A structuring of the hypertexts' space organisation according to semantic concepts, like conceptual maps or overviews, has received much scientific interest (e.g. Müller-Kalthoff & Möller, 2003; Potelle & Rouet, 2003; Scott & Schwartz, 2007). A helpful semantic organisation is usually based on conceptual categories (topics) with no or few cross-links between categories (e.g., hierarchy). A hierarchical structure is mainly made up of organizational links that organize the information, whereas a network structure is made up of relational links that stress relevant information, for example definition, generalization, similar information, etc., (Mohageg, 1992). Hence, giving information on the semantic organisation of hypertext content (i.e. organizational links) should limit the cognitive requirements (i.e. extraneous cognitive load) imposed by structural and conceptual disorientation, and allow more cognitive resources to be spent on effective processes for learning (i.e. germane cognitive load). However, the guidance effects provided by hierarchical structures may be moderated by the learners' prior domain knowledge. Although as reported below, the research is not always consistent.

For learners with low prior domain knowledge, different studies have shown a positive effect of hierarchical structures on navigation or learning. A hierarchical structure favors the building of a well organised representation of the hypertext macrostructure, and thus, helps develop a good representation of the topics, the concepts and their relationships (De Jong & Van der Hulst, 2002; Dee-Lucas & Larkin, 1999; Müller-Kalthoff & Möller, 2003; Potelle & Rouet, 2003; Puntambekar, Stylianou, & Hübscher, 2003). A hierarchical structure may guide the reading sequence (Calisir & Gurel, 2003; de Jong & van der Hulst, 2002), support coherent reading paths (Dee-Lucas & Larkin, 1995), limit perceived disorientation (Beasley & Waugh, 1995; Last, O'Donnell, & Kelly, 2001) and improve navigation efficacy (Park & Kim, 2000). However, some studies have not found any effect of this type of structure, and authors suggest that hierarchical structures would be more helpful if the hypertext was larger containing more text sections because it would be more demanding (Brinkerhoff, Klein, & Koroghlanian 2001; Jonassen, 1993).

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For high prior knowledge learners, non-linearity of hypertexts is usually expected to be efficient (e.g., Chen, Fan, & Macredie, 2006; Jacobson & Spiro 1995). Hypertexts support learning by allowing the high prior knowledge learners to use their own mental models to process information and organize their reading paths. Although, some empirical studies have shown that providing a structure with relational links does not support learning performance for high prior knowledge learners (Mishra & Yadav, 2006; Müller-Kalthoff & Möller, 2003; Potelle & Rouet, 2003; Shapiro, 1999).

In hypertexts that provide relational links (i.e., a network structure), high prior knowledge learners seem to be less disoriented than low prior knowledge learners (Jenkins, Corritore, & Wiedenbeck, 2003; McDonald & Stevenson, 1998b; Mishra & Yadav, 2006). Nevertheless, other research did not find any effect of prior knowledge on subjective disorientation (e. g. Calisir & Gurel, 2003; Müller-Kalthoff & Möller, 2003).

Despite some of the mixed findings reported above, investigations of navigational behaviors have shown that high prior knowledge users conduct more detailed and in-depth explorations than low prior knowledge users (Carmel, Crawford, & Chen, 1992; Jenkins et al., 2003). High prior knowledge learners also use more structured navigational patterns (Mishra & Yadav, 2006) and less sequential exploration than low prior knowledge learners (MacGregor, 1999). A few studies have confirmed the existence of a causal relationship between navigational behaviors and learning performances for high prior knowledge learners (Patel, Drury, & Shalin, 1998).

To conclude, whereas low prior knowledge learners need a lot of guidance (e.g., hierarchical format), high prior knowledge learners seem to be able to deal with the complexity of a network structure. This can be either because high prior knowledge learners have more cognitive resources available (due to reduced intrinsic load) so that they can handle the disorientation better, or that by actively exploring germane load is facilitated by the need to structurally/conceptually link information (prior knowledge enables this process to occur). This relation between prior knowledge and guidance is consistent with the research into the expertise reversal effect, which has found that for experts, guidance, which is highly effective for novices, may no longer contribute to learning, or may even hamper learning (Kalyuga, Ayres, Chandler, & Sweller, 2003; van Gog, Paas, & van Merriënboer, 2008).

1.4. Purposes and hypotheses

In our study, the investigations focused on the effect of prior domain knowledge and the hypertext structure on learning outcomes, cognitive load (mental effort and disorientation) and navigation (reading paths followed by the learners).

For low prior knowledge learners, it was hypothesized (Hypothesis 1) that learning from a non-linear document structured with relational links (i.e. network structure) would be more demanding than learning from a non-linear document structured with organizational links (i.e. hierarchy). A network structure would require learners to establish semantic relations between the information nodes, whereas a hierarchical structure would provide semantic information about the relations between nodes and their relationship with the global structure of the document. It was predicted that learners would follow coherent reading sequences based on the organizational links (i.e. systematic exploration of the hierarchy) and thus maintain coherence between information nodes. Therefore, it was expected that a hierarchical structure would produce lower mental effort and less disorientation (i.e. extraneous cognitive load) than a network structure. It was expected that the learning performance would be higher in the hierarchical structure and particularly for the acquisition of the semantic relations between concepts in different nodes.

For high prior knowledge learners, it was hypothesized that prior knowledge would provide relevant resources to cope with the demand of a network structure. Therefore no effect of the structure was expected on the disorientation. A network structure would lead high prior knowledge learners to engage in active explorations of the document based on their schemata to plan and construct their reading sequences. In comparison to the hierarchical structure, one of two possible outcomes was expected. Either there would be no difference because prior knowledge would reduce extraneous cognitive load (i.e. disorientation) significantly to enable learning to occur, but not necessarily promote additional germane cognitive load (Hypothesis 2a), or the network structure would lead to a better learning performance because the cognitive requirements of the network structure would promote inferential activity (germane load) based on prior knowledge and would help build a deep mental model of the content (Hypothesis 2b). In both cases it was predicted that for disorientation there would be no difference between structures. However, in terms of cognitive load, it was expected that for Hypothesis 2a there would be no difference, but for Hypothesis 2b cognitive load would increase in the network structure due to increased germane load.

2. Method

2.1. Participants

Fifty-four future high school biology teachers in a teacher training college volunteered to participate in the experiment (14 males and 40 females). Their mean age was 25.3 years ($SD = 2.83$). All participants had an undergraduate qualification in biology.

2.2. Materials

2.2.1. Learning task and materials

A course in the domain of virology was designed for the experiment. The course dealt with the multiplication cycle of a virus (coronavirus type). The coronavirus was chosen because it was not familiar to the participants and would allow new knowledge acquisition. The content was made up of different concepts (elements, events/actions). Seventeen text sections (pages) were used (total number of words = 681). Two conceptual maps were designed that reflected the structure of the document: one hierarchical and the other a network structure (see Fig. 1). The hierarchical structure gave a short presentation of the coronavirus at level 1, the macro-information at level 2 (the virus and the main stages), the sub-elements and sub-stages at levels 3 and 4. The macro-information was made up of four groupings: (a) description of the virus, (b) entrance of the virus into the cell, (c) production of virus' elements and (d) departure of the new viruses from the cell. The network structure presented the concepts without any groupings, but the concepts were connected by relational links reflecting semantic relations, like causal, temporal or spatial relations (rather than organizational links as in the hierarchical structure). In both structure conditions, clicking on a link of the conceptual map opened a text section and then a link below the text led back to the map where a new concept (or the same concept) could be opened. It should be noted that the material is called a non-linear document rather than a hypertext because it was not as extended and complex as a classical hypertext (e.g., there were no hyperlinks in the texts, one always had to return to the map). Thus the material was more controlled than an extended hypertext. However, the document is characterised by the non-linear-

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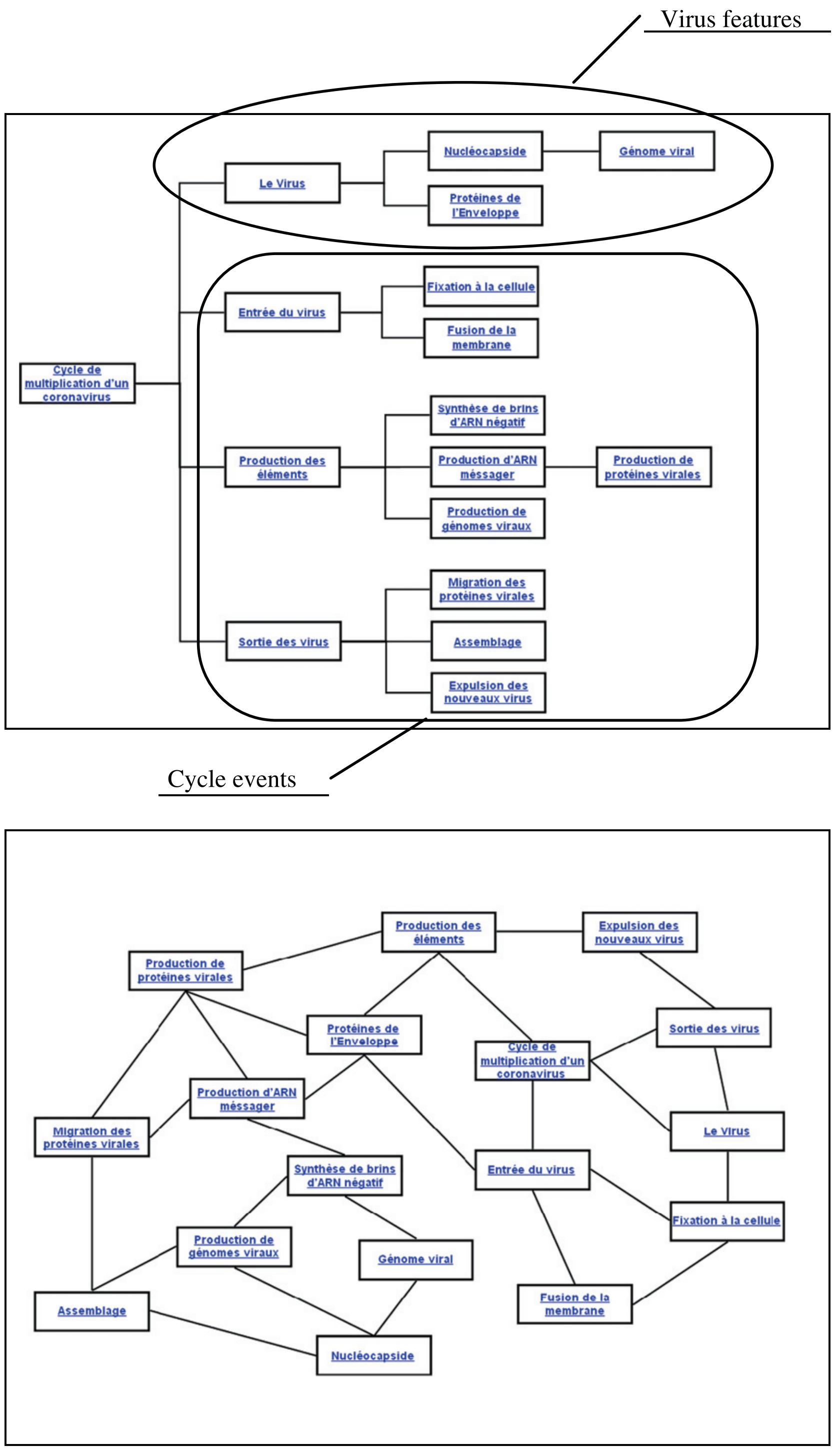

Fig. 1. Conceptual maps (hierarchical on the left and network on the right).

ity of information as in a hypertext, and thus would required similar processing.

2.2.2. Prior domain knowledge test

The learners' prior knowledge in the domain of the virus cycles was assessed. Because expert knowledge is organised on the basis of deep principles of the domain (Chi, Feltovich, & Glaser, 1981; Dee-Lucas & Larkin, 1988), the task required the participants to write the principles and particularities of the viruses' multiplication cycles. By means of an open-ended question, they were instructed to indicate the main stages and sub-stages of the different multiplication cycles of viruses and to enumerate the different particularities they knew (i.e., the differences between the viruses and their cycles). Each stage and element recorded was given one point (max: 49). For instance, a participant who indicated that the viruses' genome was RNA−, RNA+, single-stranded DNA, and double-stranded DNA, received four points (one for each type of genome). For the stages, a participant who indicated that viruses were released after budding, exocytosis or lysis received three points (one for each stage/event). Based on the median score of the prior knowledge test (*Md* = 8; from 0 to 27), the participants were split into two groups: the high prior knowledge group (HPK group, *N* = 26) and the low prior knowledge group (LPK group, *N* = 28).

2.2.3. Learning performance

Two tests were used to assess learning performance: a free recall task and a statement-judging task. In the free recall test, participants were instructed to recall all the information that they had learnt from the course. The explicit ideas from the text sections were coded (each correct idea received one point; max: 71).

The statement judging task allowed the testing of two types of knowledge: factual and conceptual knowledge. *Factual knowledge* corresponded to objects, events and definitions that learners had acquired from individual text sections (nodes). *Conceptual knowledge* corresponded to rules or principles allowing the linking of concepts, and thus the prediction and explanation of a phenomenon or system, reflecting a deeper understanding. Answering the factual knowledge items required the participants to remember information explicitly mentioned in a text section consisting of one or two sentences. For example, concerning information in one node "*The nucleocapsid is made up by the virus' genome and the structural proteins N. The nucleocapsid is fixed to the virus' envelop thanks to proteins M*" the following statement had to be judged "*the protein N is a protein which belongs to the virus' envelop*" (correct answer = wrong). Answering the conceptual knowledge items required participants to establish conceptual links between two or more text sections (the participants had to possess a representation of implicit relations between concepts). For example, from information conveyed by two different nodes "*The viral proteins S, E and M are led to the endoplasmic reticulum. Then, being in the reticulum, the proteins are inserted into the reticulum's membrane...*" and "... *The protein N is linked to the RNA to produce the nucleocapsid. After its construction, the nucleocapsid goes to the endoplasmic reticulum and is enclosed in the reticulum's membrane*..." the following statement had to be judged "*All the viral proteins are unified in a new virus in the endoplasmic reticulum*" (correct answer = true).

Eleven statements assessed factual knowledge and 13 statements assessed conceptual knowledge. Participants were therefore presented with 24 statements about the corona virus cycle. The statements were displayed on a screen by the software Inquisit 2.0.51002 (Millisecond Software LLC, 2005). The participants were instructed to judge the statements by indicating "right", "wrong", or "I do not know" (included to avoid random answers) by pressing keys P (upper right corner), A (upper left corner), or spacebar (low middle), respectively. Each correct judgement scored one point. This judgement task was administered before and after learning in order to test the knowledge gain. The statements used for the pre-test were similar to the statement used for the post-test, but they were offered in reverse order. The factual and conceptual knowledge gains were computed by subtracting pre-test scores from post-test scores.

2.2.4. Mental effort and disorientation measures

The invested mental effort to learn the material was measured using the subjective 9-points rating scale designed by Paas (1992) ("Please indicate how much mental effort you invested in studying the learning task": 1 = "very, very low", 9 = "very, very high").

Feelings of disorientation were measured using a part of the set of subjective rating scales designed by Ahuja and Webster (2001). Five 9-points rating scales (1 = "very, very low", 9 = "very, very high") were selected to assess conceptual disorientation rather than structural disorientation. Farris, Jones, and Elgin (2002) confirmed that users give greater importance to semantic information than spatial information to construct a mental model of a web site. As we were interested in the construction of meaning from a non-linear document and not in the construction of a physical representation of the document, the scales were modified according to our material, and assessed the perceived difficulty. The scales corresponded to "your difficulty with: (a) understanding the relationships between the different pages of the document was [rating of 1–9], (b) knowing which page to consult next was [rating of 1–9], (c) knowing your location in the lesson was [rating of 1–9], (d) finding information that you have already read was [rating of 1–9], and (e) understanding the sequence of the virus' multiplication cycle was [rating of 1–9]". The five disorientation scales showed a strong reliability (Cronbach's α = .90). A mean disorientation score for each participant was computed from the five rating scales.

2.2.5. On-line recording tools: coherence of the reading sequences

The activity of the participants was recorded with the freeware "Traceur Internet 0.02.0027" (INRP, 2000). The temporal-causal coherence of the reading sequences (i.e. navigating respecting the temporal and causal relations between elements and events of the virus' multiplication cycle exposed in the different text sections) was studied here because research on text comprehension has highlighted the fact that readers run causal inferences from instructional texts (van den Broek, Young, Tzeng, & Linderholm, 1999; Vidal-Abarca, Martinez, & Gilabert, 2000). The level of coherence of the reading sequences was calculated measuring the distance between the participants' reading sequence and the chronological sequence of the multiplication cycle of the virus. For instance, when a participant jumped from node A to node C or from node C to node A, the distance was recorded as "2". A jump respecting exactly the chronology (e.g. from node D to node E or node E to D) received a distance score of "1". The coherence score of the reading sequence equals the mean distance score. Therefore the more the coherence score tended to "1", the more the reading sequence was coherent.

2.3. Design and procedure

Participants were tested in groups of 1–8. The duration was roughly 50 min. The prior knowledge test was administered at least 24 h before the experimental phase. The participants answered the open questions about the viruses' multiplication cycles. The HPK and LPK participants were randomly assigned to the hierarchical structure condition or to the network structure condition. A *t*-test indicated that the average prior knowledge score did not differ significantly between the hierarchical structure group ($M = 8.27$, $SD = 6.29$, $N = 26$) and the network structure group ($M = 9.82$, $= 7.78$, $N = 28$), $t(52) = .802$, $p > .10$.

In the experimental session, participants first judged the pre-test statements. They were informed that the statements concerned the coronavirus. The pre-test scores confirmed that the participants were not very familiar with the coronavirus: $M = 1.26$ ($SD = 1.15$) for the factual knowledge statements (max: 11) and $M = 0.96$ ($SD = 1.35$) for the conceptual knowledge statements (max: 13). Then, participants were instructed to learn the materials in order to understand the coronavirus' multiplication cycle. They had 17 min maximum to learn the materials. Before starting, they were informed that they would have to answer questions about the content after the learning task. After learning the text, participants rated, respectively the global mental effort scale and the disorientation scales. Finally, they performed the free-recall task (10 min) followed by the post-test judgement task (enough individual time to complete each question).

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3. Results

3.1. Learning outcome measures

Means and standard-deviations of learning performances are given in Table 1. A 2 × 2 ANOVA (type of structure X level of prior knowledge) conducted on the number of recalled ideas during the free recall task shows neither an effect of the structure $F(1,50) = 1.05$, *ns*, nor an effect of the level of prior knowledge, $F(1,50) = 2.44$, *ns*. However, the ANOVA revealed a significant interaction, $F(1,50) = 5.11$, $MSE = 269.28$, $p < .05$, Cohen's $f = 0.32$. Pairwise comparisons were computed and revealed that whereas there was no significant effect of the structure for the HPK group, $F(1,50) < 1$, *ns*, the LPK group had higher recall scores in the hierarchical structure than in the network structure, $F(1,50) = 5.62$, $MSE = 295.75$, $p < .05$, Cohen's $d = 0.67$. The tests indicated also that the HPK group outperformed the LPK group in the network condition, $F(1,50) = 7.61$, $MSE = 401.29$, $p < .01$, Cohen's $d = 0.78$, whereas there was no difference between these groups in the hierarchical structure, $F(1,50) < 1$, *ns*.

For the statement-judging task, a 2 × 2 ANOVA performed on the factual knowledge gain scores (post-test factual knowledge scores – pre-test factual knowledge scores), yielded no significant effects (all $p > .10$). A 2 × 2 ANOVA conducted on the conceptual knowledge gain scores (post-test conceptual knowledge scores – pre-test conceptual knowledge scores), showed no significant effect of the structure, $F(1,50) = 1.37$, *ns*, nor interaction, $F(1,50) = 2.18$, *ns*. However, the HPK group as might be expected, gained more conceptual knowledge ($M = 7.88$, $SD = 2.25$) than the LPK group ($M = 5.79$, $SD = 3.58$), $F(1,50) = 6.65$, $MSE = 58.67$, $p < .05$, Cohen's $f = 0.35$.

3.2. Learning process measures

3.2.1. Learning mental effort and feelings of disorientation

The data of mental effort and disorientation ratings is presented in Table 1. A 2 × 2 ANOVA performed on the mental effort rating did not indicate any effect (all $p > .10$). A 2 × 2 ANOVA performed on the mean disorientation scores indicated that the network structure caused higher disorientation ($M = 4.60$, $SD = 1.32$) than the hierarchical structure ($M = 3.13$, $SD = 1.27$), $F(1,50) = 17.23$, $MSE = 29.57$, $p < .001$, Cohen's $f = 0.58$. No effect of prior knowledge was observed, $F(1,50) < 1$, *ns*, and, contrary to our expectation, there was no significant interaction, $F(1,50) < 1$, *ns*.

3.2.2. Coherence of the reading sequences

Table 1 shows the data for the coherence scores of the reading sequences. High scores indicate a low coherent reading sequence. A 2 × 2 ANOVA conducted on the coherence scores, showed as expected, that the hierarchical structure supported more coherent reading sequences ($M = 1{,}57$, $SD = 0.37$) than the network structure ($M = 2.93$, $SD = 0.60$), $F(1,50) = 101.98$, $MSE = 24.36$, $p < .001$, Cohen's $f = 1.35$. There was no effect of prior knowledge, $F(1,50) < 1$, *ns*. However, in confirmation of our predictions, a significant interaction was observed, $F(1,50) = 4.08$, $MSE = 0.98$, $p < .05$, Cohen's $f = 0.16$. Pairwise comparisons were computed and showed that the reading sequences were more coherent in the hierarchy structure than in the network structure for the LPK group, $F(1,50) = 76.48$, $MSE = 18.27$, $p < .001$, Cohen's $d = 2.47$, and for the HPK group, $F(1,50) = 31.38$, $MSE = 7.50$, $p < .001$, Cohen's $d = 1.58$. But as can be seen from Table 1 and the effects sizes, the effect is much larger in LPK group. As expected, the HPK group tended to construct more coherent reading sequences than the LPK group in the network structure, $F(1,50) = 3.63$, $MSE = 0.87$, $p = .062$, Cohen's $d = 0.54$. In the hierarchical structure, there was no effect of prior knowledge, $F(1,50) < 1$, *ns*.

4. Discussion

The experiment addressed the effects of prior domain knowledge and the structure of an interactive conceptual map on learning performances, cognitive load (mental effort and disorientation) and navigation. It was hypothesized (Hypothesis 1) for low prior knowledge learners that a network structure (relational links between nodes) would result in high disorientation (i.e. extraneous cognitive load) and hamper construction of semantics relations between information nodes. For high prior knowledge learners, it was predicted that they would cope much better with the requirements of a network structure. Prior knowledge would constitute a resource to construct coherent reading sequences and to reduce disorientation. In addition, compared to a hierarchical structure it was hypothesized that a network structure would not support better outcomes (Hypothesis 2a) or conversely would support better outcomes because it would promote additional germane cognitive load (Hypothesis 2b).

The results corroborated Hypothesis 1 in that low prior knowledge learners benefited from the hierarchical structure to integrate information in memory as shown by the free recall performance. This beneficial effect for low prior knowledge learners replicates previous findings (Calisir & Gurel, 2003; de Jong & van der Hulst, 2002; Potelle & Rouet, 2003; Shapiro, 1999). In accordance with previous studies, the hierarchical structure supported coherent reading sequences (de Jong & van der Hulst, 2002) and limited perceived disorientation (Beasley & Waugh, 1995). These results tend to show that a hierarchal conceptual map would help low prior knowledge learners to avoid ineffective processing for learning. Such a structure assists learners in making decisions in navigation and maintaining coherence during reading. These findings are consistent with the cognitive load theory and confirm that disorientation may explain the effect of the type of structure for low prior knowledge learners. Nevertheless contrary to our expectations, the type of structure affected neither mental effort nor conceptual learning. In the former case, equivalent mental effort ratings between the experimental groups may be explained by free resources in working memory being allocated to learning from the text (germane load) rather than to navigation (extraneous cognitive load).

Table 1
Means and (standard deviations) of the learning outcome measures, the mental effort ratings, the disorientation ratings and the coherence score of reading sequences.

	LPK learners		HPK learners	
	Network $n = 14$ *M* (*SD*)	Hierarchy $n = 14$ *M* (*SD*)	Network $n = 14$ *M* (*SD*)	Hierarchy $n = 12$ *M* (*SD*)
Number of recalled ideas	19.71 (6.12)	26.21 (9.76)	27.29 (6.24)	24.83 (6.04)
Factual knowledge gain (max = 11)	7.57 (2.47)	7.71 (1.81)	8.64 (1.33)	7.75 (1.81)
Conceptual knowledge gain (max = 13)	4.71 (3.89)	6.86 (3.01)	8.00 (1.61)	7.75 (2.90)
Mental effort (1–9)	5.64 (1.22)	6.28 (1.27)	5.71 (0.91)	5.58 (0.67)
Feeling of disorientation (1–9)	4.39 (1.02)	3.21 (1.20)	4.83 (1.56)	3.03 (1.40)
Coherence scores of reading sequences	3.10 (0.58)	1.47 (0.37)	2.75 (0.58)	1.67 (0.36)

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Indeed similar levels of cognitive load may be devoted to entirely different processes (see Paas & Van Gog, 2006), although this argument must be treated with some caution as only the free recall data supports this possibility. The lack of significant effect on the conceptual knowledge may be due to high values of standard errors. Furthermore the lack of these expected effects may be due to the fact that the non-linear document used in the present study was less extended than classical hypertexts, thus it required less relational processing between nodes (Brinkerhoff et al., 2001). Indeed the disorientation ratings were quite low ($M = 3.89$). These low ratings suggest that, although disorientation depends on the type of structure, it does not interfere so much with the effective processing for learning. The study should be replicated with more extended non-linear documents requiring more relational processing.

As far as the high prior knowledge learners were concerned, the experiment did not attest any effect of the type of structure on learning performance. This result corroborates Hypothesis 2a that prior knowledge would help learners to compensate the lack of guidance in a network structure (i.e. the lack of organisational links) but not necessarily promote additional learning (Hypothesis 2b). This lack of structure effect on learning for the high prior knowledge learners replicates previous findings (Mishra & Yadav, 2006; Potelle & Rouet, 2003; Shapiro, 1999).

Interestingly, analyses conducted in the network structure condition showed that prior knowledge constituted resources to process the network demands. Firstly, high prior knowledge supported higher conceptual learning in the network structure (although not significant but in the right direction) and this is consistent with previous findings showing the positive effects of prior knowledge only on deep learning (Shapiro, 1999). Secondly, the investigations of the learners' reading sequences provided some evidence for the existence of active explorations based on prior domain knowledge, as high prior knowledge learners followed more coherent reading sequences than lower prior knowledge learners in the network condition, suggesting they were able to produce inferences based on their knowledge structures to find relations between nodes and construct reading paths semantically coherent. These findings are important because they highlight how high prior knowledge learners compensate the lack of organisational cues provided by hierarchical structures. They are able to process non-linear information building active reading sequences based on semantic coherence of the contents.

Concerning the cognitive load and disorientation measures, the present findings indicated that measuring cognitive load using a different measure to the standard CLT instrument (Paas, 1992) was more sensitive to differences. Under the present conditions, a mental effort measure was not sensitive enough to differentiate between the different effects, whereas measures of disorientation identified differences according to the type of structure. Contrary to the study conducted by Calisir and Gurel (2003) and in agreement with others studies (McDonald & Stevenson, 1998b; Müller-Kalthoff & Möller, 2003), the disorientation measures highlighted the difficulties caused by a network structure in comparison to a hierarchical structure. In constructing a pathway and a mental representation of the information space, a network structure imposes high processing demands. While previous works considered only global cognitive load (e.g. Zumbach & Mohraz, ~~in press~~) or disorientation (e.g. Otter & Johnson, 2000), the present study underlines the need to take into account both mental effort and disorientation in research on learning from hypertexts.

Overall, the results about the relations between prior knowledge, reading sequences and disorientation in the network condition did not corroborate all our assumptions. Although the learners' prior knowledge supported coherent reading sequences in the network structure, the assessed disorientation was not reduced with greater prior knowledge. An explanation may be that disorientation is dependent on different levels of processing. Only one level of processing was investigated in this study (i.e. processing of reading sequences) whereas other levels of processing of non-linear documents may be highly demanding. For example, disorientation may also reflect difficulties caused by processing of structural information. Future investigations should examine the processes linked to cognitive load and disorientation, and distinguishing the processes supporting the construction of a global representation of the information organisation from the processes supporting the construction of relations between two nodes. New assessment methods such as eye tracking could provide more information on the attentional processes in the reading task or selection task (van Gog, Kester, Nievelstein, Giesbers, & Paas, in this issue). In addition, combining navigation data with verbal protocols (van Gog, Paas, Van Merriënboer, & Witte, 2005) should help to identify the type of reading strategies and processes as well as their relations with cognitive load and disorientation.

5. Uncited reference

Kirschner (2002). Q2

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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. (2006). Utilisation d'un hypermédia et apprentissage: Deux activités concurrentes ou complémentaires ? [Using hypermedia and learning: Two concurrent or complementary activities?]. *Psychologie Française [French Psychology], 51*, 5–23.
Beasley, R. E., & Waugh, M. L. (1995). Cognitive mapping architectures and hypermedia disorientation: An empirical study. *Journal of Educational Multimedia and Hypermedia, 4*, 239–255.
Brinkerhoff, J. D., Klein, J. D., & Koroghlanian, C. M. (2001). Effects of overviews and computer experience on learning from hypertext. *Journal of Educational Computing Research, 25*, 427–440.
Calisir, F., & Gurel, Z. (2003). Influence of text structure and prior knowledge of the learner on reading comprehension, browsing and perceived control. *Computers in Human Behavior, 19*, 135–145.
Carmel, E., Crawford, S., & Chen, H. (1992). Browsing in hypertext: A cognitive study. *IEEE Transactions on Systems, Man, and Cybernetics, 22*, 865–884.
Chen, S. Y., Fan, J.-P., & Macredie, R. D. (2006). Navigation in hypermedia learning systems: Experts vs. novices. *Computers in Human Behavior, 22*, 251–266.
Chi, M. T. H., Feltovich, P. J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Science, 5*, 121–152.
Conklin, J. (1987). Hypertext: An introduction and survey. *IEEE computers, 20*(9), 17–41.
Cress, U., & Knabel, O. B. (2003). Previews in hypertexts: Effects on navigation and knowledge acquisition. *Journal of Computer Assisted Learning, 19*, 517–527.
de Jong, T., & van der Hulst, A. (2002). The effects of graphical overviews on knowledge acquisition in hypertext. *Journal of Computer Assisted Learning, 18*, 219–231.
Dee-Lucas, D., & Larkin, J. H. (1988). Novice rules for assessing importance in scientific texts. *Journal of Memory and Language, 27*, 288–308.
Dee-Lucas, D., & Larkin, J. H. (1995). Learning from electronic texts: Effects of interactive overviews for information access. *Cognition & Instruction, 13*, 431–468.
Dee-Lucas, D., & Larkin, J. H. (1999). Hypertext segmentation and goal compatibility: Effects on study strategies and learning. *Journal of educational multimedia and hypermedia, 8*, 279–313.
DeStefano, D., & LeFevre, J.-A. (2005). Cognitive load in hypertext reading: A review. *Computers in Human Behavior, 23*, 1616–1641.
Dillon, A., & Gabbard, R. (1998). Hypermedia as an educational technology: A review of the empirical literature on learner comprehension, control and style. *Review of Educational Research, 68*, 322–349.
Dillon, A., Mc Knight, C., & Richardson, J. (1993). Space – the final chapter or why physical representation are not semantic intentions. In C. Mc Knight, A. Dillon, &

J. Richardson (Eds.), *Hypertext. A psychological perspective* (pp. 169–191). Chichester: Ellis Horwood.

Farris, J. S., Jones, K. S., & Elgin, P. D. (2002). Users' schemata of hypermedia: What is so spatial about a website? *Interacting with Computers, 14*, 487–502.

Foltz, P. W. (1996). Comprehension, coherence and strategies in hypertext and linear text. In J.-F. Rouet, J. J. Levonen, A. Dillon, & R. J. Spiro (Eds.), *Hypertext and cognition* (pp. 109–136). Mahwah, NJ: Lawrence Erlbaum.

Gall, J. E., & Hannafin, M. J. (1994). A framework for the study of hypertext. *Instructional Science, 22*, 207–232.

Gerjets, P., Scheiter, K., Opfermann, M., Hesse, F. W., Eysink, T. H. S. (in this issue). Learning with hypermedia: The influence of representational formats and different levels of learner control on performance and learning behaviour. *Computers in Human Behavior*, xx, xxx–xxx.

Gerjets, P., & Scheiter, K. (2003). Goal configurations and processing strategies as moderators between instructional design and cognitive load: Evidence from hypertext-based instruction. *Educational Psychologist, 38*, 33–41.

INRP (2000). *Traceur Internet* 0.02.0027 [software]. France: Montrouge.

Jacobson, M. J., Maouri, C., Mishra, P., & Kolar, C. (1996). Learning with hypertext learning environments: Theory, design, and research. *Journal of Educational Multimedia and Hypermedia, 5*, 239–281.

Jacobson, M. J., & Spiro, R. J. (1995). Hypertext learning environments, cognitive flexibility, and the transfer of complex knowledge: An empirical investigation. *Journal of Educational Computing Research, 12*, 301–333.

Jenkins, C., Corritore, C. L., & Wiedenbeck, S. (2003). Patterns of information seeking on the Web: A qualitative study of domain expertise and Web expertise. *IT & Society, 1*(3), 64–89.

Jonassen, D. H. (1989). Mapping the structure of content in instructional systems technology. *Educational Technology Research and Development, 29*(4), 36–43.

Jonassen, D. H. (1993). Effects of semantically structured hypertext knowledge bases on users knowledge structures. In D. A. a. R. J. McKnight C (Ed.), *Hypertext: A psychological perspective* (pp. 153–168). New York: Ellis Horwood.

Jonassen, D. H., & Wang, S. (1993). Acquiring structural knowledge from semantically structured hypertext. *Journal of Computer-Based Instruction, 20*(1), 1–8.

Kalyuga, S., Ayres, P., Chandler, P., & Sweller, J. (2003). The expertise reversal effect. *Educational Psychologist, 38*, 23–31.

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

Last, D. A., O'Donnell, A. M., & Kelly, A. E. (2001). The effects of prior knowledge and goal strength on the use of hypertext. *Journal of Educational Multimedia and Hypermedia, 10*, 3–25.

MacGregor, S. K. (1999). Hypermedia navigation profiles: Cognitive characteristics and information processing strategies. *Journal of Educational Computing Research, 20*, 189–206.

McDonald, S., & Stevenson, R. J. (1998a). Effects of text structure and prior knowledge of the learner on navigation in hypertext. *Human Factors, 40*, 18–27.

McDonald, S., & Stevenson, R. J. (1998b). Navigation in hyperspace: An evaluation of the effects of navigational tools and subject matter expertise on browsing and information retrieval in hypertext. *Interacting with Computers, 10*, 129–142.

Millisecond Software LLC (2005). Inquisit 2.0.51002 [Computer software]. Seattle, WA: Millisecond Software LLC.

Mishra, P., & Yadav, A. (2006). Using hypermedia for learning complex concepts in chemistry: A qualitative study on the relationship between prior knowledge, beliefs, and motivation. *Education and Information Technologies, 11*, 33–69.

Mohageg, M. F. (1992). The influence of hypertext linking structures on the efficiency of information retrieval. *Human Factors, 34*, 351–367.

Müller-Kalthoff, T., & Möller, J. (2003). The effects of graphical overviews, prior knowledge, and self-concept on hypertext disorientation and learning achievement. *Journal of Educational Multimedia and Hypermedia, 12*, 117–134.

Niederhauser, D. S., Reynolds, R. E., Salmen, D. J., & Skolmoski, P. (2000). The influence of cognitive load on learning from hypertext. *Journal of Educational Computing Research, 23*, 237–255.

Otter, M., & Johnson, H. (2000). Lost in hyperspace: Metrics and mental models. *Interacting with Computers, 13*, 1–40.

Paas, F. (1992). Training strategies for attaining transfer of problem-solving skill in statistics: A cognitive load approach. *Journal of Educational Psychology, 84*, 429–434.

Paas, F., Renkl, A., & Sweller, J. (2003). Cognitive load theory and instructional design: Recent developments. *Educational Psychologist, 38*, 1–4.

Paas, F., & Van Gog, T. (2006). Optimising worked example instruction: Different ways to increase germane cognitive load. *Learning and Instruction, 16*, 87–91.

Paas, F., & Van Merriënboer, J. J. G. (1994). Instructional control of cognitive load in the training of complex cognitive tasks. *Educational Psychology Review, 6*, 351–371.

Park, J., & Kim, J. (2000). Contextual navigational aids for two World Wide Web systems. *International Journal of Human–Computer Interaction, 12*, 193–217.

Patel, S. C., Drury, C. G., & Shalin, V. L. (1998). Effectiveness of expert semantic knowledge as a navigational aid within hypertext. *Behaviour & Information Technology, 17*, 313–324.

Potelle, H., & Rouet, J.-F. (2003). Effects of content representation and readers' prior knowledge on the comprehension of hypertext. *Journal of Human–Computer Studies, 58*, 327–345.

Puntambekar, S., Stylianou, A., & Hübscher, R. (2003). Improving navigation and learning in hypertext environments with navigable concept maps. *Human–Computer Interaction, 18*, 395–428.

Rouet, J.-F., Britt, M. A., Mason, R. A., & Perfetti, C. A. (1996). Using multiple sources of evidence to reason about history. *Journal of Educational Psychology, 88*, 478–493.

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

Schnotz, W., & Heiß, A. (in this issue). Semantic scaffolds in hypermedia learning environments. *Computers in Human Behavior*, xx, xxx–xxx.

Scott, B. M., & Schwartz, N. H. (2007). Navigational spatial displays: The role of metacognition as cognitive load. *Learning and Instruction, 17*, 89–105.

Shapiro, A. M. (1999). The relationship between prior knowledge and interactive overviews during hypermedia-aided learning. *Journal of Educational Computing Research, 20*, 143–167.

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* (pp. 605–620). Mahwah, New Jersey: Lawrence Erlbaum.

Spiro, R. J., Feltovich, P. J., Jacobson, M. J., & Coulson, R. L. (1991). Cognitive flexibility, constructivism, and hypertext: Random access instruction for advanced knowledge acquisition in ill-structured domains. *Educational technology research and development, 31*(5), 24–33.

Sweller, J. (2003). Evolution of human cognitive architecture. In B. Ross (Ed.). *The psychology of learning and motivation* (Vol. 43, pp. 215–266). San Diego: Academic Press.

Sweller, J., van Merriënboer, J., & Paas, F. (1998). Cognitive architecture and instructional design. *Educational Psychology Review, 10*, 251–296.

van den Broek, P., Young, M., Tzeng, Y., & Linderholm, T. (1999). The landscape model of reading: Inferences and the online construction of a memory representation. In H. Oostendorp & S. R. Goldman (Eds.), *The construction of mental representations during reading* (pp. 71–98). Mahwah, NJ: Lawrence Erlbaum.

van Gog, T., Kester, L., Nievelstein, F., Giesbers, B., & Paas, F. (in this issue). Uncovering cognitive processes: Different techniques that can contribute to cognitive load research and instruction. *Computers in Human Behavior*, xx, xxx–xxx.

van Gog, T., Paas, F., & van Merriënboer, J. J. G. (2008). Effects of studying sequences of process-oriented and product-oriented worked examples on troubleshooting transfer efficiency. *Learning and Instruction, 18*, 211–222.

van Gog, T., Paas, F., Van Merriënboer, J. J. G., & Witte, P. (2005). Uncovering the problem-solving process: Cued retrospective reporting versus concurrent and retrospective reporting. *Journal of Experimental Psychology: Applied, 11*, 237–244.

Vidal-Abarca, E., Martinez, G., & Gilabert, R. (2000). Two procedures to improve instructional text: Effects on memory and learning. *Journal of Educational Psychology, 92*, 107–116.

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*, 93–130.

Wright, P. (1991). Cognitive overheads and prostheses: Some issues in evaluating hypertexts. In *Paper presented at the Proceedings of the third ACM conference on hypertext*. USA: San Antonio.

Zumbach, J., Mohraz, M. ~~(in press)~~. Cognitive load in hypermedia reading comprehension: Influence of text type and linearity. *Computers in human behavior*, 24, 875–887.

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