How hypertext fosters children’s knowledge acquisition: The roles of text structure and graphical overview

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**Article info**

**Abstract**

Children in primary and secondary school are asked to go on the Internet for school purposes while research on hypertext has scarcely investigated how children process and learn from hypertext. We therefore examined how hypertext influences children’s knowledge acquisition from expository text. A group of 71 Dutch children (13 years old) from one secondary school for pre-university education participated in the study. In a within-subjects design with four conditions, we compared: regular linear text, regular text with overview, hypertext, and hypertext with overview. Children’s (a) navigation (i.e., reading time and navigation pattern) and (b) learning (i.e., multiple choice knowledge questions and mind maps) was measured. Although reading times did not differ, the children navigated less linearly in both hypertext conditions than in the regular text with overview condition. The four types of text led to the same deep understanding as measured on the text base level. Analyses of the mind maps, however, showed the children to construct richer situation models after reading hypertext or hypertext with an overview relative to regular linear text and regular text with overview. We therefore conclude that hypertext fosters a deeper level of information processing when appropriately designed relative to regular linear text.

**Introduction**

Rapid developments in the field of computers and the Internet are increasingly influencing contemporary education. A huge amount of information is easily accessible via the Internet, which means that readers are being confronted with more and more hypermedia documents and hypertext (Fesakis, Sofroniou, & Mavroudi, 2011). Given that the structure and content of a hypertext system are not specified and unpredictable, there is a greater degree of reader control, because the reader has to determine his/her own pathway, which places additional demands on the cognitive resources and executive function. Executive function encompasses cognitive flexibility; students must shift their behavior and cognition to the changing demands of hypertext to form concepts. Hypertext studies have indeed shown that high levels of prior domain knowledge and process knowledge enhance focused behavior as goal directed navigation which may facilitate learning from hypertext (Salmerón, Baccino, Cañas, Madrid, & Fajardo, 2009; see also Amadieu, Tricot, & Mariné, 2009). During the reading process they must select and decide about the reading order of the links in a hypertext document to establish a coherent reading path, based on the reader’s experience, interest, prior knowledge, comprehension and reading goals (Landow, 1992; Salmerón, Kintsch, & Cañas, 2006; Waniek, 2012). To date, research on the reading of hypertext has mostly focused on adults (DeStefano & LeFevre, 2007). Studies regarding children and the Internet have focused on their information search strategies and not their learning (see for review, Kuiper, Volman, & Terwel, 2005). In the present study, we therefore investigated children’s comprehension of reading regular text versus hypertext, either with or without the support of a graphic overview.

**1. Models of hypertext learning**

Two models of learning from regular text have shaped research on hypertext processing and are mainly based upon theories of reading and learning (Shapiro & Niederhauser, 2004). In the Construction-Integration Model (Kintsch, 1988), it is assumed that the reader must relate representations of the ideas from a text and hypertext at three static stages in order to comprehend the text and actually learn from it. First of all, the reader has to rely on his/her own knowledge and information from the text base. The reader then decides to make a coherent reading path, based on prior knowledge, importance, and the reader’s interest. Second, the reader must build a coherent reading path, based on prior knowledge, interest, and the reader’s experience. Third, the reader must understand the text and actually learn from it.

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The second model of learning from regular text is based on the Cognitive Flexibility Theory (Shapiro & Niederhauser, 2004; Spiro, Coulson, Feltovich, & Anderson, 1988), which postulates for reading hypertext, that the reader must flexibly integrate prior knowledge with multiple knowledge structures from ill-structured hypertext document into existing knowledge and reorganize the existing knowledge structures in order to build a situation model (Spiro, 1991). When new information does not fit into existing schema, it is assumed that the reader must readjust and restructure the existing schema or create new schema to accomplish flexible and transferable knowledge (Shapiro & Niederhauser, 2004; Smith-Gratto, 2000).

Both models describe prior knowledge as a key factor for the creation of a situation model and attainment of a sufficiently deep understanding of new material. According to the Construction-Integration Model, low-prior knowledge readers may have to go through a static comprehension process to develop a situation model (Shapiro & Niederhauser, 2004). However, in Cognitive Flexibility Theory, it is assumed that mental representations are constructed and combined in order for deep and flexible learning to occur. According to the Cognitive Flexibility Theory, children have to reconstruct and alter their situation model for deep learning. In line with these two current models of learning from hypertext, active reading engagement is viewed as a necessary condition for such meaningful learning (Kintsch, 1998; Shapiro & Niederhauser, 2004).

Both, semantic and structural knowledge is relevant for navigation on the Internet (Juvina & Van Oostendorp, 2008). For readers with low prior knowledge, reading comprehension scores and free recall performance have been found to be higher after reading a hierarchically organized hypertext as opposed to a networked hypertext, because the former provides a more coherent navigation path than the latter (Amadieu et al., 2009; Calisir, Eryazici, & Lehto, 2008). Finally, hypertext reading time has been found to positively correlate with hypertext learning in adults (Niederhauser, Reynolds, Salmen, & Skolmoski, 2000). The reader must monitor his/her comprehension and cope with the hypertext demands. However, many readers of hypertext fail to regulate their learning (Kerr & Symons, 2006). Drawing mind maps may help in this case. There is a great deal of evidence that drawing mind maps enhances deep processing of the information and may enhance learning (Nesbit & Adesope, 2006). Adolescents or undergraduate students create a mental model or knowledge representation of the hypertext in the form of a schema (Otter & Johnson, 2000; Waniek, 2012). The interest of measuring readers mental models grows and one method to measure the mental model of a reader are mind maps or knowledge maps (O’Donnell, Danserea, & Hall, 2002). A mind map represents ideas as node-link associations and is an organizational strategy for comprehending text. Specifically, mind maps have no conventional linear reading order and may be therefore especially suited in reconstruction the situation model of a hypertext. This method of measuring learning is relevant to hypertext learning. This method of measuring learning is relevant to hypertext learning: regarding the Cognitive Flexibility Theory a reader may access a hypertext from multiple perspectives resulting in flexible mental models, which should be reflected in the mind map of the reader. However, children are low-prior knowledge readers and may have to go through the static comprehension process described in the Construction-Integration Model for knowledge construction to develop a situation model and comprehend a hypertext. Particularly with regard to the Cognitive Flexibility Theory, children have to reconstruct and alter their situation model flexible as demanded by the hypertext design and integrate their prior knowledge with new information for deep processing and meaningful learning. Therefore, children may construct different mental models as well as mind maps from hypertext compared to linear text.

1.2. Role of graphical overviews

Graphical overviews are often provided in hypertext in order to invoke prior knowledge and facilitate the construction of a situation model. The presence of graphic overviews can facilitate learning (Salmerón et al., 2009). They may help the reader to avoid disorientation and overly high cognitive demands (for review, see DeStefano & LeFevre, 2007; Wright, 1991). The organization of the main ideas in a text certainly guides navigation through the text and the construction of a situation model (Madrid, Van Oostendorp, & Melguizo, 2009; Salmerón et al., 2006). According to schema theory (Anderson & Pearson, 1984), words presented in an overview can serve as cues for comprehension and support the building of relations between concepts. And in several studies, graphical overviews in hypertext documents have indeed been shown to foster the building of a macrostructure for the text and a coherent reading order (Amadieu et al., 2009; Müller-Kalthoff & Müller, 2005; Naumann, Richter, Flender, Christmann, & Groeben, 2007; Potelle & Rouet, 2003; Salmerón et al., 2006; Vörös, Rouet, & Pléh, 2011).

Graphical overviews can be static or dynamic with hyperlinks in the overview and arranged alphabetically or hierarchically. A graphical overview with a matching spatial layout is better recalled than an alphabetically structured graphical overview because it facilitates spatial mapping process (e.g., an index; Dee-Lucas & Larkin, 1995; Vörös et al., 2011). Research has shown hierarchically structured overviews to lead to better learning performance than unstructured, networked, or alphabetically structured overviews (Amadieu et al., 2009). And while hierarchical overviews in hypertext have been found to foster the same level of understanding as list overviews for undergraduate students with either high or low prior knowledge (Hofman & Van Oostendorp, 1999; Salmerón et al., 2009), hierarchical overviews read at the beginning promoted better comprehension of hypertext than list overviews, particularly in sixth-graders with low prior knowledge (Naumann et al., 2007; Salmerón & García, 2011).

1.3. A developmental perspective

Most research has focused on the hypertext reading comprehension strategies of skilled readers who are proficient readers of linear text, mainly adolescents or undergraduate students. The degree to which those findings hold for children with far less reading experience is thus unclear. Due to less content knowledge but also process knowledge, it can be assumed that the hypertext reading strategies of children will differ from those of adults (Salmerón & García, 2011). Puntambekar and Goldstein (2007) examined the effects of navigable overview versus a list of concepts on adolescent’s comprehension and they found the form of the overview (i.e., concept map vs. outline) does not make a difference for the learning of pure facts but readers in the navigable overview condition nevertheless showed deeper and richer text comprehension. When Kerr and Symons (2006) examined the effects of linear text presented in printed form versus reading from a computer monitor on children’s (grade five) reading times, comprehension, and recall, they found the children to read faster from paper. However, no evidence was found for differences in the reading strategies of the children in the two conditions (Kerr & Symons, 2006).

When Salmerón and García (2011) examined the hypermedia reading comprehension of sixth graders (11 years old) from a Spanish public primary school, they found the skilled readers to be able to use a cohesive hyper-linking strategy, which positively correlated with hypertext reading comprehension in turn. Skilled
1.4. The present study

Previous studies have examined children's navigation and link selection strategies in hypertext but not the influence of different (hyper)text structures on the children's learning (i.e., knowledge acquisition and building of a situation model), navigation patterns or reading times. In the present study, we investigated how 13-year-old Dutch children learn from text in four experimental conditions: text structure (regular linear text versus hypertext) and presence or absence of graphical overview. The children's learning outcomes and situation models were compared across conditions in addition to their reading times and navigation patterns in order to answer the following questions.

Q1: How do text structure and the presence of graphical overviews influence children's text comprehension and construction of situation models?
Q2: How do text structure and the presence of graphical overviews influence children's reading times and patterns of navigation through a text?
Q3: How do children's patterns of navigation in both hypertext conditions relate to their construction of situation models?

2. Method

2.1. Participants

Seventy-one children (36 girls, 35 boys, \(M_{\text{age}} = 13.1\) years, age range: 11–13 years) from three seventh grade classes from a single Dutch secondary school for pre-university education participated in the experiment. Two other participants were excluded because of dyslexia and very low scores on a technical reading skills test. Some children had incomplete data, resulting missing data at random. The participants had normal or corrected-to-normal vision and none reported any difficulties in reading the texts from the computer screens. The children were unfamiliar with the purpose of the experiment. All parents or primary caregivers provided written consent.

2.2. Text materials

All children read four text conditions: regular linear text (RLT), regular text with an overview (RTO), hypertext (HT), and hypertext with an overview (HTO) (see Appendix A and Figs. A1–A4). The RLT condition contained regular linear electronic text with four headings, six subheadings, and page numbers. The children could navigate between the pages of the text by clicking on forward and backward buttons. The RTO condition contained the regular linear electronic text supplemented with a navigable overview with a hierarchical structure at the top of each page. The overview consisted of the 10 headings from the linear text (i.e., four chapter headings and six subchapter headings). The children could navigate between the pages in this condition by clicking on one of the 10 hyperlinks in the overview. The HT condition contained the regular linear electronic text plus 10 hyperlinks within the text that were identical to the keywords in the text headings. The links were standard blue and underlined; when activated by clicking on them, they changed from blue to gray. A “home” button on the final page also enabled the reader to go back to the first page in this condition. The HTO condition contained the hypertext supplemented by the same hierarchical overview as in the other overview condition. Just as in the other overview condition, the words in this overview were links; this meant that this condition contained a total of 20 links.

According to the within-subjects design, all participants read all four text conditions; however, to exclude an effect of text topic, the four text conditions were designed in four different text topics, resulting in 16 text materials (4 text types \(\times 4\) topics). The text materials were four expository geography texts from textbooks written for this age (The Reader's Digest, 2002): Oceania, Russia, South America, and South Africa. The text conditions RLT, RTO, HT and HTO as well as the four text topics were counterbalanced and presented in a random order to reduce the possibility of order effects. Hence, each child read four different text types with four different topics; for example one child read in the RLT condition about Oceania, in the RTO condition about Russia, in the HT condition about South-America and in the HTO condition about South-Africa. Another child read in the RLT condition about Russia, in the RTO condition about South-America, in the HT condition about South-Africa and in the HTO condition about Oceania. The texts had a hierarchical structure, which was distributed across 10 pages and an average of 974 words (SD = 36.21). The topic was introduced on the first page and then followed by three main chapters and two subchapters per main chapter.

Microsoft Internet Explorer 8 for Windows® XP was used to present the text materials. Children read the texts in full screen modo to prevent them from searching for other things on the Web. And while the children read the texts in the four conditions, their navigation operations were recorded using the freeware CamStudio™ screen recorder and their reading times were registered in log-files.

2.3. Learning measures

2.3.1. Knowledge tests

To assess the children's knowledge after reading a particular text, 20 multiple choice (MC) questions with four possible answers were constructed for each of the four texts. Ten of the MC questions referred to explicit knowledge and ten referred to implicit knowledge. The explicit questions were factual or related verbatim to the text (example of an explicit question: “The Kagu in Oceania belongs to which species group? (a) Mammals, (b) Birds, (c) Reptiles, (d) Insects”); the implicit questions required the children to make inferences and draw conclusions (example of an implicit question: “Why is a tree in Oceania called breadfruit tree? (a) Because the fruits are the same for the people in Oceania as fresh bread is for us, (b) Because the fruit tastes similar to bread, (c) Because the fruits look like cinnamon buns (d) Because many birds brood in the trees). A Web-based application (PERSUS) was used to administer the MC questions. In a pilot study, 67 sixth-grade children from five different Dutch schools read the four texts in a paper version of the RLT condition and answered the MC questions for the four texts. The pilot results showed a sufficient alpha for the explicit MC questions (\(\alpha = .84\)) and implicit MC questions (\(\alpha = .73\)). Based on the pilot results, conspicuous features in text passages and MC questions were revised. For the prior knowledge test, four questions (two implicit and two explicit questions per topic) were randomly chosen out of 20 MC questions for each of the four texts. These 16 MC questions were used to assess the children's amount of prior knowledge.

2.3.2. Mind maps

To assess the situation models constructed by the children, they were asked to draw a mind map following the reading of each text. To ensure that the children were familiar with the concept of mind mapping and to reduce differences in experiences the children received one lesson (40 min) in mind mapping by the first author. During this lesson the children
learned by means of examples of good and bad mind maps that a mind map arranges links and concepts around a central key word and is known to help readers organize and visualize new information (Davies, 2011). For an open mind map, the creator chooses the relevant concepts him/herself and arranges them on the basis of his or her knowledge. Fig. 1 shows a mind map from a child who participated in this experiment. The content of all the mind maps was checked for concepts and/or associations outside the scope of the four texts to control for content. Two raters counted the number of concepts (words) as well as the number of hierarchies. A hierarchy was the combination of at least a first and second level concept link. Concepts placed next to the central key represented first level links. Concepts then linked to the first level links represented second level links. Concepts linked to the second level links represented third level links. The extremities or last concepts of a hierarchy were counted to determine the total number of hierarchies. The scoring of the mind maps was based on the scoring system of Evrekli, Inel, and Balim (2010). First level links were assigned two points, second level with four points, and third level links six points. The total number of points for the mind maps thus indicated their complexity.

For the present study we employed one undergraduate student of Educational Science to rate the number of concepts, of hierarchies and complexity of the mind maps. The student was previously familiar with mind maps and the idea that concepts that were arranged around a central key word help readers to organize and visualize information. In addition, the lesson for the children was shown to the student for a deeper insight. The undergraduate pedagogic student was inexperienced in coding, but received one hour of training in scoring mind maps. The first author did the second rating. Because of the standardized scoring method, the raters had no disagreement during the training session.

To measure the inter-rater reliability of the mind map scoring system we calculated kappa $k$ for the first and second level of the mind maps. For the first level of the mind maps, a kappa of $k = .95$ was calculated, indicating almost perfect agreement between the two raters (of which one was the first author of this paper). For level 2 kappa was $k = .84$, indicating excellent agreement between the two raters (Cohen, 1960).

### 2.4. Navigation measures

#### 2.4.1. Reading time

For each text, the reading time was recorded when the child logged onto the first page and ended when the child clicked on the button “finished reading”.

#### 2.4.2. Navigation pattern

The length of the reading path was determined from the log-files and consisted of the number of pages clicked on by the children to be read. Based on the hierarchical structure of the texts, the degree of linearity was also determined (Amadieu, Tricot, & Mariné, 2010). To begin with, a coherence score was computed. A score of 1 point was assigned when a jump was made to a text section that was deeper in the hierarchy and/or a jump between two text sections belonging to the same category within the same level of the hierarchy. To calculate the linearity score, the coherence score was divided by the total number of pages read. A linearity score of 1 indicates a maximally linear reading pattern. The number of pages read and the linearity scores were also calculated for the first 10 pages read as this reading is known to be crucial for identification of the macrostructure of a text or the “meaningful whole” (Kintsch & Van Dijk, 1978).

### 2.5. Child characteristics

Two child characteristics were measured as control variables. First, the children’s technical reading skills were assessed with a Dutch silent Lexical Decoding Test consisting of 120 disyllable words (van Bon, 2007). Some of the words are nonsense or non-existing words. During the test, the participant has to cross out as many nonsense words as possible during the time limit of one minute. Second, the children’s computer literacy was measured with a computer and Internet experience questionnaire with seven items ranging from a 2 point scale up to a 5 point scale (Citogroep, [http://toetswijzer.kennisnet.nl](http://toetswijzer.kennisnet.nl)).

### 2.6. Procedure

The experiment was conducted as a within-subjects design during five lessons of 45 min each, distributed across 5 days. The
experimental sessions were run in the computer room of the school with three groups of up to 27 children that were measured at once with the same materials and procedure. At pretest on the first day, the children answered 16 MC questions to assess the amount of prior knowledge. Their reading skills and computer literacy were also assessed.

In the experimental phase, the children received written instructions, which were further clarified via oral explanation by the researcher. They were instructed to read each text carefully and without a time limit so that they would be able to answer 20 MC questions about the text afterwards. The children read one of the four text versions at random in one session. They had to click on a “finished reading” button on the last page of the RTO, HT and HTO versions. This procedure was used to determine the overall reading duration (in ms); it also prevented the children from searching in the text to answer the MC questions. After reading a text, the children answered the MC questions and drew a mind map about the text they had read. The four sessions were held across a period two weeks.

3. Results

3.1. Analyses of learning outcomes

The pretest scores for the children’s prior knowledge as measured using a subset of the MC questions (16 questions; $M_{\text{correct}} = 5.72$, $SD = 1.94$) confirmed that they had little or no prior knowledge of the four geography topics. Furthermore, the children had good technical reading skills ($M = 103.03$, $SD = 14.28$) and had a lot of experience working with a computer and the Internet ($M = 23.67$, $SD = 1.56$). Table 1 shows the learning outcomes for the four text conditions.

3.1.1. Knowledge test

A repeated measures ANOVA with Text Type (RLT, RTO, HT, HTO) and Question Type (explicit, implicit) as between-subjects variables revealed no main effect of Text Type, ($F(3,162) = 2.39$, $p = .063$, $\eta^2_p = .05$). Pairwise comparisons using Bonferroni correction indicated higher knowledge scores in the RTO condition than in the HT condition ($p = .023$). The RLT, HT, and HTO conditions did not differ significantly from each other (all $p > .05$). There was also a main effect of Question Type: The children answered more explicit questions correctly than implicit questions, ($F(1,54) = 6.38$, $p = .015$, $\eta^2_p = .11$). There was no interaction between Text Type and Question Type ($F < 1$).

3.1.2. Mind maps

The mind maps were analyzed in a series of repeated measures ANOVAs with Text Type as the within-subjects variable and the following dependent variables: number of concepts; number of hierarchies; number of first, second, and third order concept links; and complexity. Main effects were further analyzed using post hoc pairwise comparisons with Bonferroni correction (see Table 2 for an overview).

3.1.2.1. Number of concepts. There was a main effect of Text Type, ($F(3,108) = 3.47$, $p = .019$, $\eta^2_p = .09$). Further analyses showed this effect to be due to the children using slightly more concepts in the HTO condition than in the RTO condition ($p = .059$).

3.1.2.2. Number of hierarchies. The text types differed statistically with regard to the number of hierarchies found in the mind maps constructed by the children following their reading, ($F(3,99) = 2.72$, $p = .048$, $\eta^2_p = .08$). The children constructed significantly more hierarchies in the HTO condition than in the RTO condition ($p = .031$). No significant differences were found between the other text conditions.

3.1.2.3. Number of first, second, and third level links. The data of the first, second, and third level links were non-normally distributed and analyzed with a nonparametric ANOVA (Friedman’s). The number of first and second level links did not differ significantly between the four for text conditions (all $p > .05$). However, the third level links differed statistically depending on Text Type, ($\chi^2(3) = 24.89$, $p < .001$). Post hoc analyses with Wilcoxon tests showed that, the mind maps drawn in the HTO condition had more third level links than those drawn in both the RLT condition

<table>
<thead>
<tr>
<th>Measure</th>
<th>RLT $M$ (SD)</th>
<th>RTO $M$ (SD)</th>
<th>HT $M$ (SD)</th>
<th>HTO $M$ (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge test</td>
<td>Explicit MC questions</td>
<td>6.38 (2.09)</td>
<td>6.62 (1.78)</td>
<td>6.02 (2.18)</td>
</tr>
<tr>
<td>Mind maps</td>
<td>Implicit MC questions</td>
<td>5.29 (1.89)</td>
<td>5.68 (1.88)</td>
<td>5.19 (2.05)</td>
</tr>
<tr>
<td>N concepts</td>
<td>14.18 (7.40)</td>
<td>14.47 (7.06)</td>
<td>14.93 (7.67)</td>
<td>14.76 (6.33)</td>
</tr>
<tr>
<td>N hierarchies</td>
<td>7.40 (5.01)</td>
<td>7.92 (4.15)</td>
<td>7.72 (4.88)</td>
<td>8.25 (3.87)</td>
</tr>
<tr>
<td>N concept links</td>
<td>First level</td>
<td>4.17 (2.09)</td>
<td>3.41 (1.69)</td>
<td>3.66 (1.31)</td>
</tr>
<tr>
<td>Second level</td>
<td>5.91 (3.39)</td>
<td>5.87 (2.63)</td>
<td>5.74 (3.27)</td>
<td>6.22 (2.25)</td>
</tr>
<tr>
<td>Third level</td>
<td>3.23 (3.87)</td>
<td>4.02 (3.86)</td>
<td>4.14 (3.74)</td>
<td>4.90 (3.98)</td>
</tr>
<tr>
<td>Complexity</td>
<td>50.84 (30.40)</td>
<td>54.26 (26.89)</td>
<td>56.74 (31.64)</td>
<td>60.17 (26.76)</td>
</tr>
</tbody>
</table>
Also for the complexity of the mind maps, a significant main effect of Text Type was found. \( F(3,102) = 7.35, p < .001, \eta^2_g = .18 \). The children produced more complex mind maps in the HTO condition relative to both the RLT condition \( (p = .002) \) and the RTO condition \( (p < .001) \) but not relative to the HT condition. The HT condition also differed from the RTO condition \( (p = .048) \) with more complex mind maps in the former than in the latter.

3.2. Analyses of navigation outcomes

Table 3 shows the outcomes for the process measures for the four text conditions.

### 3.2.1. Reading time

A Friedman’s ANOVA with Text Type (RLT, RTO, HT, HTO) as the within-subjects variable was conducted on Reading Time (see Table 3). Children spent the same amount of time reading the four text documents \( (p = .210) \).

### 3.2.2. Length of reading path

A Friedman’s ANOVA for the total length of the reading path indicated significant differences for Text Type, \( \chi^2(3) = 49.19, p < .001 \). The children revisited significantly more pages in the HT condition and had accordingly longer reading paths than in all of the other conditions \( (all \, ps < .05) \). They also revisited more pages in the HTO condition than in the RTO condition \( (p = .001) \).

### 3.2.3. Linearity of navigation pattern

The children have – by definition – to read linearly in the RLT condition; all of the linearity scores in this condition were therefore 1 (see Table 3). Hence, the linearity scores in the RLT condition were non-normally distributed. To examine whether the number of links in the text conditions influenced the linearity of the navigation pattern or not, a Friedman’s ANOVA on the navigation data was conducted with text condition (RLT, RTO, HT, HTO) as a within-subjects variable. The linearity of the children’s navigation patterns differed significantly across the four text conditions, \( \chi^2(3) = 86.50, p < .001 \). Post hoc analyses with Wilcoxon tests showed all of the text conditions to differ significantly from each other. The linearity of reading was significantly higher in the RLT condition than in the HT condition \( (z = -5.44, p < .001) \), the RTO condition \( (z = -5.91, p < .001) \), and the HTO condition \( (z = -5.78, p < .001) \). HT was also read more linearly than both RTO \( (z = -3.75, p < .001) \) and HTO \( (z = -4.53, p < .001) \). The children’s reading in the RTO condition was also significantly more linear than their reading in the HTO condition \( (z = -2.13, p = .033) \).

### 3.2.4. First 10 navigation clicks

Regarding the children’s first 10 navigation clicks (see Table 3), the Friedman’s ANOVA revealed significant differences between the first 10 clicks in all four of the text conditions, \( \chi^2(3) = 36.71, p < .001 \). Post hoc analyses using Wilcoxon tests showed significantly more linearity for the first 10 navigation clicks in the RLT condition compared to: the HT condition \( (z = -4.43, p < .001) \), the RTO condition \( (z = -4.58, p < .001) \), and the HTO condition \( (z = -4.29, p < .001) \). HT was also read significantly more linearly compared to both RTO \( (z = -2.82, p = .005) \) and HTO \( (z = -2.16, p = .031) \). The linearity of the first 10 navigation clicks did not differ significantly for the HTO condition versus the RTO condition, however \( (z = -0.35, p = .725) \).

We also examined the number of different pages read on the first 10 navigation clicks. A repeated measures ANOVA revealed significant differences between the text conditions, \( F(3,147) = 123.62, p < .001, \eta^2_p = .72 \). Post hoc comparisons showed the number of different pages read by the children during the first 10 navigation clicks to be lower in the HT condition than in all of the other conditions: RLT, RTO, and HTO \( (all \, ps < .001) \). The RLT, RTO, and HTO conditions did not differ statistically from each other \( (ps < .05) \). In the HT condition, the children apparently decided to go back to difficult or unclear text passages rather than to new passages, thus, they switched more often between the same pages resulting in higher linearity scores than in the other text conditions. In the other text conditions (i.e., RLT, RTO, and HTO), the children read almost all 10 pages during the first 10 navigation clicks. This means that the children build better macrostructures in not only the RTO and HTO conditions but also the RTO condition compared to the HT condition.

### 3.2.5. Relations between navigation outcomes and learning outcomes

The linear and quadratic relations between the length of the reading paths and the outcome variables for only the HT and HTO conditions were calculated and are summarized in Table 4. The linearity scores in the RLT condition were all 1 and could therefore not be analyzed here. The RTO condition was also disregarded here because there were no hyperlinks in this text condition that could influence navigation during reading. The comparison of the HT and HTO conditions showed mostly non-significant relations between the length of the reading path and the children’s total knowledge scores following the reading of the texts \( (all \, ps > .05) \). The one exception to this was the HTO condition where a linear relation was found \( R^2 = 0.285, p < .001 \): Those children who visited more pages in this condition also answered more of the MC knowledge questions correctly.

With regard to the number of concepts in the children’s mind maps, no significant relationships were found \( (all \, ps > .05) \). Similarly, in the HT condition, there were no significant relations between the length of the reading paths and the number of hierarchies in the children’s mind maps. However, in the HTO condition, a quadratic relation was found \( R^2 = 0.237, p = .006 \).
the number of visited pages increased to an optimum, the number of hierarchies in the mind maps also increased; further increases in the number of pages visited, however, was associated with mind maps with less hierarchies.

When the possible relations between the length of the reading path and the number of first-level concept links occurring in the children’s mind maps were analyzed, once again: no significant associations were found in the HT condition. However, a quadratic relation was found in the HTO condition (\( R^2 = 0.213, p = .004 \)), such that when the number of visited pages increased to an optimum, the number of first-level concepts of the mind maps also increased; further increases in the number of pages visited, however, was associated with an increasing number of first-level concepts.

Furthermore, a quadratic relation was found between the length of the reading path in the HTO condition and the complexity of the children’s mind maps in this condition (\( R^2 = 0.194, p = .007 \)); When the number of visited pages increased to an optimum, the complexity of the mind maps also increased; further increases in the number of pages visited, however, was associated with mind maps of a reduced quality.

In sum, the significant quadratic relationships that we found showed the number of hierarchies, the number of first level concept links, and the complexity of the children’s mind maps to generally increase as the number of pages visited by the children in the HTO condition increased; further increases in the number of pages visited, however, were associated with decreased scores and thus a lower quality of mind map in the HTO condition.

With regard to the children’s mind maps, the results show the children to produce more complex and detailed mind maps in the hypertext and hypertext with overview conditions than in the regular text and regular text with overview conditions; research by Puntambekar and Goldstein (2007) supports this finding. It can thus be tentatively concluded that hypertext and hypertext with overview elicits a more active mode of information processing. These results are in line with the generally positive findings found for hypertext comprehension (Dee-Lucas & Larkin, 1995). The complex mind maps of the children in the hypertext with overview condition may also be due to the fact that not only the links in the text but also the nonlinear structure of the hypertext prompted the children to adopt and focus more on navigation strategies to create a suitable situation model.

Our second research question focused on the navigation outcomes as children’s reading time and navigation patterns. First, we examined reading time and found no significant differences for the different types of text. This suggests that the children had no orientation problems in the different conditions and the hypertext and hypertext with overview conditions in particular. They did not spend more time reading all of the pages in one particular condition.

We next examined navigation pattern and found the children with the shortest navigation patterns to be in the regular text with overview condition. The advantage of having a graphical overview also manifested itself in the two hypertext conditions. Once again, the navigation patterns were shorter for hypertext condition with an overview as opposed to no overview. When provided a clear navigation overview, the children in our study thus revisited fewer pages and were therefore presumably able to focus on the content of the textbooks more than when such no overview was provided.

Closer inspection of the navigation strategies used by the children in the different conditions indicates that RLT was read most linearly, followed by RLO, HT, and HTO in that order. This result is in line with what we expected while, the increase in flexibility from regular text to hypertext and text with a navigable overview to hypertext with a navigable overview reduced the linearity or coherence of the children’s reading path. Children may thus adopt a less linear reading order when reading hypertext as opposed to regular linear text or regular text with a graphical overview (Madrid et al., 2009). The results with regard to the first 10 navigation clicks show the overview conditions to also be read less linearly compared to conditions without an overview. To fully understand this finding, the number of pages that the children actually read should be taken into consideration. We found that the children in the regular linear text condition, regular linear text with overview condition, and hypertext with overview condition to generally read all of the pages during their first 10 clicks. However, in the hypertext condition, the children read fewer pages during their

### Table 4
Linear and quadratic relation results for length of reading path and outcome variables in two hypertext conditions.

<table>
<thead>
<tr>
<th>Measure</th>
<th>HT</th>
<th>HTO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(sum of explicit and implicit questions)</td>
<td>Linear: ( R^2 = 0.004 ) (p = .576)</td>
<td>Linear: ( R^2 = 0.285 ) (p = .000)</td>
</tr>
<tr>
<td></td>
<td>Quadratic: ( R^2 = 0.017 ) (p = .489)</td>
<td>Quadratic: ( R^2 = 0.321 ) (p = .155)</td>
</tr>
<tr>
<td>Mind maps</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N of concepts</td>
<td>Linear: ( R^2 = 0.074 ) (p = .110)</td>
<td>Linear: ( R^2 = 0.062 ) (p = .132)</td>
</tr>
<tr>
<td></td>
<td>Quadratic: ( R^2 = 0.079 ) (p = .658)</td>
<td>Quadratic: ( R^2 = 0.081 ) (p = .402)</td>
</tr>
<tr>
<td>N of hierarchies</td>
<td>Linear: ( R^2 = 0.008 ) (p = .612)</td>
<td>Linear: ( R^2 = 0.045 ) (p = .207)</td>
</tr>
<tr>
<td></td>
<td>Quadratic: ( R^2 = 0.009 ) (p = .844)</td>
<td>Quadratic: ( R^2 = 0.237 ) (p = .006)</td>
</tr>
<tr>
<td>N of concept links</td>
<td>Linear: ( R^2 = 0.002 ) (p = .806)</td>
<td>Linear: ( R^2 = 0.000 ) (p = .963)</td>
</tr>
<tr>
<td>Level 1</td>
<td>Quadratic: ( R^2 = 0.003 ) (p = .832)</td>
<td>Quadratic: ( R^2 = 0.213 ) (p = .004)</td>
</tr>
<tr>
<td>Complexity</td>
<td>Linear: ( R^2 = 0.006 ) (p = .647)</td>
<td>Linear: ( R^2 = 0.002 ) (p = .794)</td>
</tr>
<tr>
<td></td>
<td>Quadratic: ( R^2 = 0.009 ) (p = .779)</td>
<td>Quadratic: ( R^2 = 0.194 ) (p = .007)</td>
</tr>
</tbody>
</table>
first 10 navigation clicks but reviewed already read pages more often than the in the other conditions. This suggests that the children in the hypertext condition adopted different navigation strategies than the children in the other conditions due to the absence of an overview. The links in the hypertext limit navigation and mean that it takes more navigation clicks to read all of the pages in the text and to construct the text base. It seems likely that the children reread more pages in the hypertext condition simply because they had to in order to activate new links. It can therefore be tentatively concluded that in the hypertext condition, the children adopted a navigation strategy that was text-driven and that the children in this condition focused more on the links present on each page than on the building of a text base.

In the present research, we also examined the relations between the navigation outcomes and the learning outcomes. A linear relationship was found between the total number of pages visited by the children during their reading and their learning outcomes in the hypertext with overview condition, with those children who visited more pages answering more of the knowledge questions correctly. A quadratic relationship was also found in the hypertext with overview condition such that when the number of visited pages increased to an optimum, the number of hierarchies, first-level concepts, and complexity of the mind maps also increased; further increases in the number of pages visited, however, was associated with mind maps of a reduced quality. Children have to read all relevant pages to comprehend the text, which explains the raising curve. However, children who do not reach the optimum of visited pages may remain longer on fewer pages. This reading behavior may show that the children who visited fewer pages were lacking reading strategies or self-regulated learning strategies that may support their reading behavior. Of special interest is the sloping curve after reaching an optimum of pages. We speculate that children who visited more than the expected optimum show no focused and goal directed reading behavior. This random clicking might indicate that the child is not able to regulate his/her learning or does not have the appropriate reading skills for reading hypertext.

No relations were found in the HT conditions between the linearity of the children’s navigation strategies and their learning outcomes. In fact, the children navigated in a highly linear manner in all four of the text conditions as indicated by the linearity scores. It can therefore be concluded that the Dutch secondary school children studied here adopted a highly linear reading strategy for non-print text and even hypertext either with or without an accompanying overview.

4.1. Conclusion

The Cognitive Flexibility Theory and the Construction-Integration Model are the theoretical frameworks of this study and more generally of hypertext learning. Our results are in line with both perspectives. They fit into the Construction-Integration Model in that the children showed to integrate new explicit information in both the regular text and hypertext condition into their existing mental models. They also fit with the Cognitive Flexibility Theory. This theory gives an explanation of meaningful learning and predicts for hypertext that the possibility for the reader to access information from multiple links and different perspectives may influence the mental model of the reader resulting in a multifaceted mental model and flexible knowledge (Shapiro & Niederhauser, 2004). In line with the Cognitive Flexibility Theory, we found children to show relatively deeper processing in hypertext as opposed to regular text conditions presumably because the hypertext and hypertext with overview conditions encouraged the adoption of active reading strategies, which led in turn to the creation of a richer situation model.

The most important finding from the present study is that hypertext and overviews both lead to the creation of richer situation models and a deeper understanding of text by children when measured via mind maps as opposed to MC questions. This finding suggests that the increased difficulty of reading hypertext either with or without an accompanying overview can have beneficial learning effects. The properties of hypertext and the coherence gaps that can arise while reading such text may force readers to adopt alternative reading strategies – reading strategies that promote active reading and somehow prompt readers to engage in relatively deeper processing of the material at hand (Kintsch, 1998).

More proficient readers may nevertheless use self-regulated learning strategies with hypertext and focus more on overviews with reduced decision making and hence workload as a result (Niederhauser et al., 2000). However, children must have the appropriate navigation and reading skills. Otherwise, more complex hypertext systems that require these additional reading activities will simply disorient and create cognitive overload (DeStefano & LeFevre, 2007). In line with this, self-regulated learning may play a major role in accounting for differences in children’s hypertext comprehension and knowledge gains (Azvedo & Cromley, 2004).

The results of the present study show the analysis of children’s mind maps to provide an effective technique for scholarly reading research. Furthermore, well-designed hypertext was clearly found to foster a deep level of information processing and thus enhance children’s learning.

4.2. Implications for design and instruction

One important consideration in designing hypertext is that, maps, outlines, menus and overviews present conceptual relationships and enhance the reader’s explicit knowledge. Low-prior knowledge readers benefit from such well-defined and structured hypertext, but highly organized hypertext can make reading passive. However, low-prior knowledge readers should be promoted to active reading and learning (Shapiro & Niederhauser, 2004). This careful consideration between reader skills and hypertext features is the major challenge for authors of hypertext. For children, well-structured and clearly navigable hypertext systems in knowledge domains that are at least somewhat familiar to the reader are called for (Amadieu et al., 2009; Zumbach & Mohraz, 2008).

Furthermore, this study was conducted in a classroom setting. Future research should focus more on independent learning situations. An explanation for the fact that we did not find reading comprehension differences in the four text conditions may be that children had enough time to read the whole document in all four text conditions. Therefore, it might be interesting to present larger hypertext documents to the children and focus more on the mental models and situation models of the reader to find differences between children’s reading comprehension.

4.3. Future research

In future studies, more advanced methodologies should be used to analyze the strategies used by children to read hypertext. Eye-tracking studies could help clarify the role of reading strategy in the comprehension of hypertext. Gaze data and fixation times could also shed light on the interplay between reading strategies and navigation strategies as well as indications of disorientation and their causes. Relating such measures to the drawing of mind maps may also shed more light on the rather large standard deviations in the different mind map measures in our study. Given that a great deal of individual variation was found in our study, future research should consider less skilled readers in order to examine the cognitive constraints on hypertext comprehension (Merdivan & Özden, 2011). Our results show that reading hypertext in-
creases cognitive flexibility and the importance of executive function as well as self-regulated learning in hypertext reading. Hypertext may produce added complexity and decrease learning if readers do not regulate their learning (Shapiro & Niederhauser, 2004). Therefore, it remains to be investigated how to teach children this skills for hypertext reading to improve their navigation behavior, which contribute to the understanding and learning from hypertext. Children currently read and learn from the Internet at a very early age, which means that future research should also examine the effects of hypertext comprehension interventions on young children's learning.

Appendix A.

References


