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Signaling in expository hypertexts compensates for deficits in reading skill

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Abstract

Expository hypertexts may contain specific types of signals such as navigable topical overviews and hyperlinks that map conceptual relationships between text contents. Two experiments with German university students ($N=130$, 75% female, mean age 25 years) were conducted to test the hypothesis that hypertext-specific signals particularly support learners with badly routinized reading skills in organizing and integrating complex learning materials. The experiments were based on naturalistic texts and essay-writing tasks typical for exam preparation. Learning outcomes were measured by characteristics of participants' essays (amount of knowledge, knowledge focusing, knowledge integration). In both experiments, a hypertext with a high amount of signaling yielded better learning outcomes than a linear text for low-skilled readers while there were no differences for high-skilled readers (ΔR^2 from .03 to .08 for the interaction). In Experiment 2, the same interaction pattern was found for hypertext with a high versus a low amount of hypertext-specific signals (ΔR^2 from .04 to .10). Moreover, a lack of signals led to less efficient navigation behavior. These results demonstrate that hypertexts equipped with hypertext-specific signals may compensate for deficits in reading skill.

Keywords: hypertext, linear text, macrostructure, reading skill, signals

Signaling in expository hypertexts compensates for deficits in reading skill

Early research on learning with linear text and hypertext has focused on global assessments of the relative effectiveness of either text structure, with overall inconsistent results indicated by a large variability of the size and direction of effects (e.g., Chen & Rada, 1996; Shapiro & Niederhauser, 2004). One more promising way to compare linear text and hypertext is looking at aptitude-treatment-interactions (Cronbach & Snow, 1977) of text and learner characteristics with the two-fold goal (a) to identify abilities that are needed to use either text structure effectively and (b) to determine which text structure is best for learners with a given set of abilities. Most researchers following this approach have argued that hypertexts offer greater degrees of freedom for self-regulated learning but are also inevitably associated with greater demands on learners' aptitudes, for example their prior knowledge, working memory capacity, or knowledge of learning strategies (Azevedo & Cromley, 2004; Foltz, 1996; McDonald & Stevenson, 1996; Wenger & Payne, 1996). The bottom line of this research seems to be that hypertexts are well-suited for learners with high abilities, whereas learners with low abilities are easily overtaxed by hypertexts and are better off with the overall stronger guidance provided by traditional linear text. In the present article, we will investigate interactions of text structure and reading skill from a very different perspective. We will argue for the proposition that hypertexts may be particularly effective as a remedy for deficits in basic reading skill because they allow for implementing specific kinds of textual signals that reduce working memory load without constraining self-regulated learning processes.

Starting from a sketch of the role of textual signals in learning from expository text and hypertext, the next sections will give an account of how basic reading skill might affect the use of these signals during learning, and elaborate on the cognitive mechanisms underlying the relationship of basic reading skill and the use of signals in hypertexts. We assume that

signals have the potential to reduce the working memory load imposed by texts and hypertexts with multiple subtopics, thereby benefiting especially learners with a low level of reading skill whose working memory capacity is already charged by inefficient sentence-level processes. This proposal implies specific interaction effects of linear text vs. hypertext and reading skill on learning outcomes and learning processes. These hypotheses were tested in two experiments with university students who worked on naturalistic text materials and learning tasks.

The Role of Signaling in Learning from Text

Signals are textual devices that do not contribute to the content of a text but make the semantic and topical structure of a text more explicit to readers (Lorch, 1989; Meyer, 1975). Topic overviews, headings, typographical cues such as boldface or italics, preview or summarizing statements, pointer expressions and sometimes also linguistic markers of semantic or rhetorical relations (Meyer, 1975) have all been referred to as textual signals that may provide guidance to the learner's processing of text contents. A broad definition of the term might even encompass specific types of topic overviews such as tables of content or advance organizers (Ausubel, 1968).

Nearly all theoretical proposals on signaling assume that signals influence learning from text in a positive way. In terms of van Dijk and Kintsch's (1983) strategy model of text comprehension, for example, signals help learners to form a coherent representation by directly fostering macrostrategies, i.e. processes that are directed at establishing the macrostructure of a text (van Dijk, 1980). The macrostructure included the main ideas conveyed by a text. It serves as a backbone for integrating more detailed information into the representation of the text content. From a slightly different perspective, the cognitive theory of multimedia learning (Mayer, 1996, 1997) posits that signals may be effective because they facilitate the application of three types of learning strategies that are involved in all kinds of

active learning. In particular, the theory assumes that signals make it easier for learners to select the information that is relevant for a given learning goal, to organize pieces of information into a coherent representation, and to integrate this information with prior knowledge (Mautone & Mayer, 2001).

By now, a multitude of studies with different types of signals provide evidence that signaling may indeed be beneficial for learning from text. Some of these studies have also demonstrated at least indirectly that signals are effective because they foster the selection, organization, and integration of text information. Evidence for effects of signals on *information selection*, i.e. the distinction of important and less important contents, comes from studies showing that signals such as headings, topical overviews, and summaries may improve the recall of the signaled macrostructural contents as well as more detailed contents associated with the macrostructure but not the recall of text information in general (Lorch & Lorch, 1996; Lorch, Lorch, & Inman, 1993). Misleading headings, on the contrary, can severely bias comprehension (Kozminsky, 1977). These findings suggest that learners use these topical signals to create a macrostructure that is used as a framework to organize incoming text information. At a more fine-grained level, Loman and Mayer (1983) have shown that preview sentences, headings, and logical connectives enhance the recall of information that is central for the conceptual structure of expository passages. At the same time, these types of signals impair the memory for non-central and verbatim information. In addition to the contents that learners can recall, text signals also influence the *organization* of the recalled information (Lorch et al., 1993; Lorch & Lorch, 1996, Experiment 2).

In lengthy and complex learning materials, topical overviews, summaries, and advance organizers help learners to identify the organization of a text, to locate task-relevant information more easily, and to construct a representation that corresponds to its global topical structure (Corkill, 1992; McEneaney, 1990; Murray & McGlone, 1997; Rouet, Vidal-

Abarca, Bert-Eboul, & Millogo, 2001). Pointer words, logical connectives and other types of linguistic markers may be used to signal conceptual and rhetorical relationships that help readers to construct a more strongly interconnected representation of the text content (Loman & Mayer, 1983; Meyer, 1975). Thus, signals seem to support the use of organizational strategies in learning both at a global and a more local level. Finally, linguistic markers signaling conceptual and rhetorical relationships (e.g., *too*, *because*, *although*) may increase the likelihood of causal and other types of bridging inferences, thereby enhancing representational coherence and the *integration* of text information and prior knowledge (e.g., Noordman, Vonk, & Kempff, 1992; Revlin & Hegarty, 1999; Singer & O'Connell, 2003).

In sum, signals seem to induce specific encoding strategies that may help learners to focus on text information that is most relevant for their learning goal and to construct a well-organized representation of the text content that is also better integrated with existing prior knowledge (Lorch & Lorch, 1995; Meyer, Brandt, & Bluth, 1980). The strongest corroboration for this assumption comes from studies based on on-line measures such as reading times and eye-tracking data. Sentences that introduce a new topic are usually read more slowly than sentences that continue a topic that has been introduced previously. However, the reading times for topic-introducing sentences are markedly shorter when an outline of the topical structure of a text is provided or when the topic shifts are signaled by the preceding text (Lorch, Lorch, & Matthews, 1985; Lorch, Lorch, Gretter, & Horn, 1987). Similarly, Hyönä and Lorch (2004) found in an eye-tracking experiment that the first-pass fixation times (the sum of the duration of all fixations on a sentence when it is read for the first time) as well as the look-back fixation times (the sum of the duration of all fixations on a sentence when readers return to the sentence) are shortened by signals. Most importantly, these studies show that signals can greatly reduce the processing demands that are imposed by topic shifts.

The Role of Signaling in Learning from Hypertext

In contrast to typical linear texts, expository hypertexts do not provide a specific sequence of contents where learners are gently guided from one subtopic to the next by rhetorical signals and other textual aids that help them to build a coherent representation of text contents. Instead, hypertexts allow but also require learners to decide which contents they want to attend and in what order they want to attend these contents during the course of a learning session. As a potential drawback, these advantages of hypertexts for self-regulated learning carry the risk of disorientation and an increase in working memory load (cognitive overhead, Conklin, 1987). Since textual signals have the potential to provide guidance, to facilitate the implementation of organizational strategies and, as a consequence, to reduce working memory load, signaling may be expected to play an even more important role in learning with hypertext than it does in learning with linear text. Except for those types of signals that presuppose a specific learning sequence (e.g., overviews or summaries), most of the signaling devices that have proven to be effective in linear texts can also be implemented in hypertexts. It must be noted, however, that these devices are implemented in a hypertext-specific way that differs in several ways from their conventional form in linear texts. One important difference is that in many cases, signaling devices in hypertexts are navigational devices at the same time. This means that they can be used to move from one part of the hypertext to another (e.g., from one content node to another content node or from a topical overview to a content page).

Two types of signals seem to be particularly well suited for hypertexts. Global navigational aids such as topic overviews, table of contents, and graphical overviews assist learners in constructing a representation of the topical and link structure of the hypertext that is essential for making effective and task-oriented navigational decisions. On a more fine-grained level, hyperlinks that allow learners to move from one content page to another, may

be used to signal conceptual or rhetorical relationships between different contents. Accordingly, the function of hyperlinks is similar to that of cross-references or linguistic markers that are used to signal conceptual or rhetorical relationships in linear texts. When implemented effectively, both types of signals, global navigational aids and hyperlinks that mirror the conceptual structure of the content domain, may ease the problems of disorientation and additional cognitive load that have been associated with hypertext use. Stated positively, these types of signals promise to provide learners with the opportunity to make full use of the advantages of hypertexts for constructive and self-regulated learning without having them to accept their potential disadvantages.

Consistent with this line of reasoning, several studies provide evidence that topical overviews (in most cases graphical overviews) are an overall effective means to enhance learning with hypertext (Dee-Lucas & Larkin, 1995; de Jong & van der Hulst, 2002; Puntambekar, Stylianou, & Hübscher, 2003). In their meta-analysis of experiments on interacting with hypertext, Chen and Rada (1996) found that hypertexts with graphical overviews allow users to navigate more effectively and also more efficiently compared to hypertexts without such overviews. Both comparisons were associated with medium effect sizes. Although this meta-analysis was not specifically concerned with learning from hypertext, its results suggest that global navigational aids support learning by improving learners' orientation and navigational decisions.

Interactions of Signaling with Reading Skill

The overall positive effects of signals on learning with linear text and hypertext notwithstanding, not all learners benefit from signaling to the same degree. Two learner characteristics essential for learning from text are prior knowledge and reading skill. For both learner characteristics, a similar pattern of aptitude-treatment interactions may be assumed, albeit for different theoretical reasons. For prior knowledge, a number of studies on learning

with hypertext found that the learning outcomes of learners with a low level of prior knowledge may be improved largely by providing clearly structured topical overviews. The already better learning outcomes of learners with a high level of prior knowledge, in contrast, are usually not enhanced further by this type of navigational aids (McDonald & Stevenson, 1998; Potelle & Rouet, 2003; Shapiro, 1999). Aptitude-treatment interactions of this kind may be explained by models of text comprehension such as the strategy model (van Dijk & Kintsch, 1983). According to these models, prior knowledge can substitute explicit textual signals in the sense that it enables learners to establish a coherent representation of the text content via efficient inference processes. These processes augment the construction of a situation model, i.e. a referential representation of the text contents that contains both text information and prior knowledge in an integrated manner (for results from experiments with linear text, see McNamara, Kintsch, Butler-Songer, & Kintsch, 1996).

Despite being a general, domain-independent cognitive ability (Perfetti, 1989), basic reading skill might play a compensatory role similar to that of domain-specific prior knowledge when an expository text or hypertext is lacking explicit textual signals. This is because learners with good basic reading skill are able to process written language in a highly efficient manner, i.e. accurately as well as fast. In particular, good readers rely on highly routinized but also highly reliable cognitive processes when they retrieve the meaning of words (e.g., Perfetti & Hogaboam, 1975), parse the syntactic structure of sentences (Nation & Snowling, 2000), integrate individual words with the sentence context (Stanovich & West, 1979) and suppress context-irrelevant word meanings (Gernsbacher & Faust, 1991). Because of the high degree of routinization in their lower-level comprehension processes, good readers can allocate a substantially larger amount of working memory capacity to resource-demanding higher-level comprehension processes than poor readers. These higher-level comprehension processes include strategies for selecting, organizing, and integrating new

topics that are hard to implement and resource-demanding in the absence of explicit signals (Lorch et al., 1987).

Owing to the fact that good readers are able to devote a larger proportion of working memory capacity to these strategies, they will often achieve good learning outcomes regardless of the amount of signaling in the learning materials. Poor readers' learning outcomes, in contrast, may be greatly improved because topical and rhetorical signals facilitate the selection, organization, and integration of learning materials, i.e. make these processes that can dramatically increase working memory load (Lorch et al., 1985, 1987; Hyönä & Lorch, 2004) less resource-demanding. In line with this reasoning, Meyer et al. (1980) found that high school students classified as poor readers could profit from topical and rhetorical signals when they had at least basic knowledge of how to use these signals, whereas the learning outcomes of those students classified as good readers did not benefit from the presence of signals. Similar results were found for college students in studies by Marshall and Glock (1978-1979) and by Kardash and Noel (2000) in a recognition task. These findings are not surprising because even in populations of relatively well trained readers (such as high school students or college students), there is a large variability in the routinization of component processes of reading comprehension (Daneman, 1997).

Rationale of the Present Experiments

For learning with hypertext, a compensatory role of reading skill and signaling has not been investigated yet. The present experiments were designed to enable direct tests of the hypothesis that a well-structured hypertext containing topical and rhetorical signals can compensate for inefficient basic reading skill. In particular, we hypothesized that reading skill would be of lesser importance when university students learned with a hypertext that contained topical and rhetorical signals, compared to types of expository texts that did not contain these signals. In Experiment 1, we compared the role of basic reading skill in learning

with a typical linear expository text to the role of reading skill in learning with a hypertext that contained topical signals in form of global navigational aids and rhetorical signals in form of hyperlinks. We expected that the greater amount of signaling in the hypertext would lead to better learning outcomes in learners with a low level of basic reading skill. Learners with a high level of reading skill, in contrast, were expected to achieve good learning outcomes with both types of learning materials.

Experiment 2 extended the design of Experiment 1 by including a hypertext from which most of the hypertext-specific topical and rhetorical signals were removed. With this design, we were able to clarify further the assumed compensatory role of reading skill and signaling. In particular, we expected learners with a low level reading skill to learn better with the well-structured hypertext that contained a large amount of signaling than with both the linear text and the hypertext that contained a small amount of signaling. A second goal of Experiment 2 was to compare the navigational behavior of learners in the hypertexts that contained a large versus a small amount of signaling. If the assumption is correct that signals support strategies for selecting and organizing the contents to be learned, it is reasonable to assume that the presence of topical and rhetorical signals in a hypertext induces a more systematic and goal-oriented navigational behavior.

In both experiments, we used complex text materials from a domain that was highly relevant for the participants' own studies. Approaching textbook length, the text materials were considerably longer than the texts that are typically used in research on textual signals. We also had participants work for several hours on naturalistic learning tasks that resembled typical study activities (such as preparing for an exam). Both methodological features should ensure that despite being laboratory experiments with a high degree of experimental control, the studies were informative concerning the role of signals in everyday learning activities.

Experiment 1

The purpose for Experiment 1 was to provide a test of the assumed compensatory function of a hypertext with hypertext-specific topical and rhetorical signals for deficits in basic reading skills. In particular, we expected an ordinal interaction effect of text structure and reading skill on learning outcomes. Compared to participants who learned with a linear text that lacked these features, the beneficial effect of reading skill on learning outcomes should be weaker or nonexistent in participants who learned with a hypertext with graphical overviews and hyperlinks that map conceptual relationships. Accordingly, we expected the hypertext to lead to better learning outcomes than the linear text in learners with a low level of reading skill, but we expected a smaller or nonexistent difference between the two text forms in learners with a high level of reading skill.

The psychology undergraduates who participated in the experiment learned either with a comprehensive expository hypertext or with a typical linear text that was identical in contents. The topic of the text material was visual perception, a subject matter that was a central part of important upcoming exams (Vordiplom) for all participants. Participants were given the task to study the learning materials for several hours with the goal to write an essay about a particular topic that they and other students could use to prepare for their exams. Participants studied the text materials with the goal to learn more about a particular topic, and later wrote an essay about this topic without having access to the text materials. In many respects, this task resembles free recall or summarizing tasks, which are frequently used in text comprehension research (e.g., Goldman, Saul, & Coté, 1995; Lorch, Pugzles-Lorch, Ritchey, McGovern, & Coleman, 2001; Stein & Kirby, 1992). However, there are also two methodological differences that are worth noting. First, the essay writing task used in the present experiment induced a specific learning goal. By this means, the experimental task more closely resembled everyday self-regulated learning that is usually goal-directed (Zimmermann, 1998). The second difference was that learners were allowed to take notes

during studying and to use these notes later when they wrote their essays. Again, this methodological feature was introduced to approximate everyday self-regulated learning as closely as possible. In self-regulated learning with comprehensive expository texts and hypertexts, note taking is a typical activity and a useful study strategy (Kauffman, 2004).

From the essays that participants produced after studying the text materials, we derived quantitative indicators of three different aspects of learning outcomes, how much knowledge learners acquired overall, how strongly they focused on the learning task, and how well they integrated the text contents with their prior knowledge. The latter two aspects of learning outcomes correspond to the facilitating function that signaling might have for strategies of information selection and integration (Mautone & Mayer, 2001).

Method

Participants

Eighty-four undergraduate psychology students (76% women) from the University of Cologne and the University of Heidelberg participated in the study. The proportion of women in the sample reflects their proportion among first year psychology students in Germany (78% in 2003, Bundesministerium für Bildung und Forschung/Federal Ministry of Education and Research, 2005, Ch.4, Table 7.1 and Table 7.3). The mean age was 25.4 years ($SD = 6.5$). Fifty participants were in their first year of studies and 30 in their second year of studies. Thirty-six participants had taken or were currently taking a course on the psychology of perception, including lessons on visual perception. Participants were paid approximately \$70 or received credit for research participation. They were recruited by postings on the psychology department's message boards and mailing list.

Text material

Hypertext. In Experiment 1, we used a comprehensive expository hypertext on visual perception that was written specifically for the a series of studies including the present

experiments (for sample pages, see the Supplemental Online Material for this article). The contents were based on standard textbooks on visual perception (e.g., Kebeck, 1994; Rock, 1998). The language of all text materials was German. The hypertext-specific signals contained in the hypertext were graphical overviews of the text structure that served as browsers at the same time and hyperlinks that corresponded to topical and conceptual relations between nodes. Examples for the latter are links to nodes on competing psychological explanations of a perceptual phenomenon, on the neural basis of a perceptual phenomenon, or on observations in a different area that could also be explained by a given theory. In total, the hypertext contained 230 nodes that were distributed over nine sections on topics such as perception of color, perception of space, perception of movement, and the neural bases of perception. It contained 86 figures.

The nodes were connected by 504 cross-reference links that linked nodes within as well as between sections. Glossary entries and references were presented as pop-up windows, which could be accessed by clicking on highlighted words in the text. Apart from the cross-reference links, the hypertext followed a hierarchical structure. Each of the nine sections could be reached from the introductory page that served as a topical overview. For each section, there was a graphical browser providing an overview of the contents of each node. A graphical overview of the hypertext's main structure that mimicked the introductory page was shown on the bottom left of each page. Additional non-hierarchical navigational aids included a dynamic table of content, a history list, a backtrack-function and a graphical browser called gallery that displayed typical figures for each chapter. A mouse click on one of these figures (e.g., a picture of the Poggendorf-Illusion) opened the respective chapter (e.g., the chapter on the Poggendorf-Illusion). All navigational aids could be used through buttons that were shown at the bottom right of each page. At the end of each node, there were links to thematically related nodes suggested for further reading. However, a linear walk

through the hypertext was not supported. For this reason, it was not possible to use the hypertext as a computerized linear text. In a survey with 20 hypertext experts, there was high agreement that the newly designed hypertext was a prototypical, well structured and usable expository hypertext (Flender & Christmann, 2000).

Linear text. Based on the hypertext, an expository linear text was constructed with identical contents (text and figures). The linear text was presented in form of a printed book (length 109 pages, including three pages of references and a 13-page glossary) with nine chapters that corresponded to the nine sections of the hypertext. The chapters were organized into different subchapters that corresponded to the nodes of the hypertext. The order of the chapters and subchapters in the linear text version mimicked the order of presentation in standard textbooks on visual perception (e.g., Kebeck, 1994; Rock, 1998). The linear text contained a table of contents at the beginning and references and a glossary at the end of the book.

Procedure and task

In a separate session two weeks before the actual experimental sessions, reading skill and prior knowledge were assessed (see *Measured variables*). The experimental sessions were run in groups of up to four participants who either received the hypertext or the linear text version of the text material. Participants were randomly assigned to either the linear text condition or the hypertext condition. The experimental sessions consisted of an introductory phase, a learning phase, and a writing phase.

Introductory phase. Participants who later on received the experimental hypertext were presented with a hypertext similar in structure, design and navigational aids, but on a different and unrelated topic (the psychology of old age). They worked on a tutorial that comprised of eight tasks, each of them designed to make participants familiar with one of the navigational aids and features of the hypertext (e.g., to navigate to the table of contents and

from there to a certain node). Additionally, at the end of the tutorial participants were asked to explore the hypertext's glossary and references. Participants in the linear text condition were provided with an equal number of tasks designed to make themselves familiar with the features the linear text provided (i.e., table of contents, references, glossary). The introductory phase lasted half an hour.

Learning phase. After they had completed the introductory phase, participants were handed out written instructions that explained to them the learning task they should engage in. The general task was to write an essay on the topic "Experiments in visual perception" in a way that other students could use the essay to prepare for an exam. The essays should cover the topic as completely as possible. For an appropriate task solution, it was necessary to select and integrate information from various parts of the hypertext into a coherent cognitive representation of the subject matter. During the learning phase subjects were allowed to take notes. The learning phase lasted for three hours.

Writing phase. After a one-hour break, participants wrote the requested essay on experiments in visual perception with a ball-pen on paper. While writing, participants had no access to the hypertext or linear text, but were allowed to use the notes they had taken during the learning phase. The writing phase lasted for three hours.

Measured variables

Learning outcomes. Learning outcomes were assessed through a content analysis of the essays produced by participants during the writing phase. The essays were divided into idea units. The interrater agreement for the segmentation into idea units was .94 (percentage of agreement, determined on the basis of three essays and the segmentation of three raters).

Three different aspects of learning outcomes were assessed:

(1) The *amount of knowledge* reflected in participants' essays was determined by counting the total number of idea units related to visual perception (including correct

inferences) for each participant's essay ($M = 188.49$, $SD = 60.28$). The median interrater reliability (Cohen's κ) was .91 (determined for a total of ten pairs out of five raters using five essays with a total of 860 idea units), a value that indicates almost perfect interrater agreement according to the recommendations by Landis and Koch (1977). As a count measure, the total number of idea units was highly skewed to the right. For this reason, we transformed the variable by applying a logarithmic transformation that normalizes the distribution (Cohen, Cohen, West & Aiken, 2003, ch. 6).

(2) The second variable *knowledge focusing* assessed to what extent participants' essays contained information that was related to the specific topic of the essay-writing task. This measure is informative because not all parts of the hypertext or linear text dealt were directly relevant for the essay-writing task. Twenty-one nodes (out of 230) of the hypertext and 26 pages (out of 109) of the linear text were directly related to experiments in visual perception. As a consequence, the task required learners to find relevant contents in the text materials and distinguish them from less relevant contents. For each participant's essay, we counted the number of idea units that dealt with experiments on visual perception ($M = 54.23$, $SD = 34.10$). The median interrater reliability (Cohen's κ) for this category was .68 (indicating good interrater agreement according to Landis & Koch, 1977). We then applied a logarithmic transformation to the number of task-related idea units and divided this value by the logarithmically transformed total number of idea units (i.e., amount of knowledge). We used this proportional measure rather than the absolute number of task-relevant idea units because it seems a better indicator of focusing that is independent of quantitative aspects of learning. A drawback of a proportional measure, however, is that it might be biased for participants with very short essays. For this reason, we checked for cases with irregular values by regressing the number of task-relevant idea units on the total number of idea units and inspecting the distribution of residuals for outliers. No irregularities were identified by

using this procedure. Amount of knowledge and knowledge focusing were largely independent from one another (Table 1).

(3) *Degree of integration* assessed to what extent participants' essays contained relevant information that was not included in the text materials and to what extent the essays reflected structuring of contents in a text-independent manner. In order to determine this variable, we counted the idea units that contained any kind of (correct and relevant) information that went beyond the original text base (inferences, references to prior knowledge, and meta-remarks about the text content such as critical evaluations of theoretical claims or empirical evidence), or that contained an inference connecting or structuring text contents (such as signaling, rhetorical explications, or goal statements, Meyer, 1975). Both types of idea units were summed up for each participant ($M = 17.91$, $SD = 12.62$). The median interrater reliability (Cohen's κ) for this category was .86 (indicating almost perfect interrater agreement according to Landis and Koch, 1977). Similar to the previous dependent variable, we applied a logarithmic transformation to the count measure and divided it by the logarithmically transformed total number of idea units. No irregular values were detected by the outlier detection procedure outlined in the previous paragraph. Degree of integration and amount of knowledge were independent from each other (Table 1).

Reading skill. Reading skill was assessed using the subtest *sentence verification* of a German-speaking instrument called ELVES (*Effizienz des Leseverstehens bei Erwachsenen nach dem Strategiemodell* [Efficiency of Reading Comprehension in Adult Readers According to the Strategy Model], Richter & van Holt, 2005). ELVES is a computer-based reading comprehension test that is designed for applications in populations of trained adult readers (such as university students). It comprises of seven subtests assessing the efficiency of microstructural (lower-level) and macrostructural (higher-level) component processes of reading comprehension as differentiated by van Dijk and Kintsch's (1983) strategy model of

text comprehension. In terms of this model, the subtest sentence verification captures interindividual differences in the efficiency of propositional strategies, i.e. reading comprehension processes that are operative on the sentence level (in particular, word recognition and semantic integration). The test consists of 15 predications (plus 5 practice items) that explicate the meaning of commonly used abstract and concrete concepts (selected on the basis of concreteness norms provided by Heupst & Hager, 1994) and vary in length (words: $M = 7$, $W = 4-9$; syllables: $M = 12$, $W = 5-16$). The predications are either true or false (e.g., *Strawberries are red and sweet-tasting vegetables*). Participants' task is to judge for each statement as quickly and accurately as possible whether it is true or false. Test scores are computed by combining accuracy and response speed (reciprocally transformed response times) for each item. As a consequence of this procedure, high scores may be obtained when a participant responds correctly and fast. In the present sample, the internal consistency (Cronbach's α) of the sentence verification subtest was .87.

The validity of ELVES in general and the sentence verification subtest in particular has been established in a number of studies (Richter & van Holt, 2005). Construct validity of ELVES was corroborated by means of confirmatory factor analyses showing that model fit was significantly impaired and no longer acceptable when subtests supposed to capture microstructural as opposed to macrostructural processes were forced to load on one single rather than two distinct latent variables. In another study, ELVES was used to predict performance in conventional paper-pencil reading comprehension tests, using expository texts from the areas of psychology and history of literature. Correlations between ELVES subtests and these measures amounted to about .40 and were not significantly lessened when prior domain knowledge was controlled for. Böhmer (2003) investigated relationships between the ELVES subtests and working memory capacity. In her study, the subtests addressing microstructural reading comprehension processes, including the subtest sentence

verification, were significantly and substantially ($r = .50$) correlated with the reading span (Daneman & Carpenter, 1981).

Prior knowledge. Prior knowledge was assessed with 25 multiple-choice items (one correct answer and three distractors), 12 of which referred to the meaning of important terms (e.g. "fovea") and 13 of which referred to empirical facts in the field of visual perception (e.g., the occlusion of objects in the visual field as a clue in spatial perception). In the present sample, the scale had an internal consistency (Cronbach's α) of .87 with a mean item difficulty of .40.

Results and Discussion

For each of the three dependent variables, we conducted multiple regression analyses with interaction terms (moderated regression analyses, Aiken & West, 1991). Text structure (hypertext vs. linear text), reading skill, prior knowledge, were entered simultaneously into the regression model before entering the interaction of text structure and reading skill. Text structure was entered as a contrast-coded dummy variable (hypertext coded with 0.5 and linear text with -0.5). Prior knowledge and reading skill were entered as z -standardized variables. Univariate descriptive statistics and correlations for all variables are reported in Table 1. Univariate descriptive statistics for all variables (unstandardized and untransformed) in each experimental condition are reported in Table 2. For the statistical tests of overall effects and main effect terms, we set the a priori α -level to .05 in both experiments. Following recommendations by Pedhazur and Schmelkin (1991, p. 558), we used an α -level of .10 for tests of interaction terms in order to ensure sufficient power for these tests. As a measure of effect size, we report the increment of explained variance (ΔR^2) for each predictor.

Equivalence of experimental groups and distribution of residuals. Prior knowledge did not differ significantly between the hypertext condition ($M = 9.81$, $SE_M = 0.76$) and the linear

text condition ($M = 8.10$, $SE_M = 0.78$), $t(83) = 1.57$, $p > .10$, (two-tailed), $d = 0.34$. Also, reading skill did not differ between the hypertext condition ($M = 18.94$, $SE_M = 0.83$) and the linear text condition ($M = 18.17$, $SE_M = 0.62$), $t(83) = 0.64$, $p > .10$, $d = 0.14$. In the regression models for all three dependent variables, residuals were distributed normally (Kolmogoroff-Smirnov-Tests with Lillefors-boundaries, for all tests $K-S-Z \leq 0.08$, $p > .20$) and displayed no heteroscedasticity when plotted against the predicted values.

Effects of text structure and reading skill on amount of knowledge. The results of the full regression model for amount of knowledge are summarized in Table 3 (left columns). There was no main effect for the control variable prior knowledge. Reading skill had a positive and medium-sized main effect. In addition, there was a main effect for text structure, indicating a small overall advantage of the hypertext over the linear text. Both main effects, however, were qualified by a medium-sized interaction of reading skill and text structure. To interpret the interaction effect, we computed simple slopes for each experimental group separately (according to Aiken & West, 1991; see Figure 1a). As predicted, there was a large positive effect of reading skill in the linear text condition ($B = 0.21$, $SE_B = 0.06$, $t(79) = 3.50$, $p < .001$, $\Delta R^2 = .13$) but no effect of reading skill in the hypertext condition ($B = 0.01$, $SE_B = 0.05$, $t(79) = 0.21$, $p = .83$, $\Delta R^2 = .00$). We also probed differences between the hypertext and linear text condition for participants on a low level of reading skill (one standard deviation below the mean) and a high level of reading skill (one standard deviation above the mean). When their reading skill was low, participants who had learned with the hypertext outperformed participants who had learned with the linear text ($B = 0.33$, $SE_B = 0.11$, $t(79) = 2.97$, $p < .01$, $\Delta R^2 = .09$). When their reading skill was high, however, participants in the hypertext and the linear text condition did not differ in amount of knowledge ($B = -0.06$, $SE_B = 0.11$, $t(79) = -0.60$, $p = .55$, $\Delta R^2 = .00$).

Effects of text structure and reading skill on knowledge focusing. The results of the regression model for knowledge focusing are summarized in Table 3 (middle columns). The control variable prior knowledge did not have a significant effect. There were a large and positive main effect for reading skill and a main effect for text structure that indicated a medium-sized overall advantage of the hypertext over the linear text. Again, these main effects were qualified further by a medium-sized interaction of text structure and reading skill. In line with the predictions, an analysis of simple slopes revealed a large positive effect of reading skill in the linear text condition ($B = 0.11$, $SE_B = 0.03$, $t(79) = 4.16$, $p < .001$, $\Delta R^2 = .17$) but no effect of reading skill in the hypertext condition ($B = 0.01$, $SE_B = 0.02$, $t(79) = 0.37$, $p = .72$, $\Delta R^2 = .00$). On a low level of reading skill (one standard deviation below the mean), participants who had learned with the hypertext were markedly better in knowledge focusing than participants who had learned with the linear text ($B = 0.18$, $SE_B = 0.05$, $t(79) = 3.84$, $p < .001$, $\Delta R^2 = .14$). On a high level of reading skill (one standard deviation above the mean), however, participants in the hypertext and the linear text condition did not differ in knowledge focusing ($B = -0.01$, $SE_B = 0.05$, $t(79) = -0.28$, $p = .78$, $\Delta R^2 = .00$).

Effects of text structure and reading skill on degree of integration. The results of the regression model for degree of integration are summarized in Table 3 (right columns). There was no significant main effect for prior knowledge and no main effect for text structure, but a large and positive main effect for reading skill. Again, this main effect was qualified by a medium-sized interaction of text structure and reading skill. As predicted, a simple slope analysis revealed a medium-sized positive effect for reading skill in the linear text condition ($B = 0.07$, $SE_B = 0.02$, $t(79) = 3.04$, $p < .01$, $\Delta R^2 = .10$), but no effect for reading skill in the hypertext condition ($B = 0.02$, $SE_B = 0.02$, $t(79) = 0.94$, $p = .35$, $\Delta R^2 = .01$). On a low level of reading skill (one standard deviation below the mean), participants in the hypertext condition showed a slightly higher degree of integration than participants in the linear text condition (B

= 0.09, $SE_B = 0.05$, $t(79) = 1.88$, $p = .06$, $\Delta R^2 = .04$), whereas on a high level of reading skill (one standard deviation above the mean), there was no difference in degree of integration between participants in the hypertext and the linear text condition ($B = -0.02$, $SE_B = 0.04$, $t(79) = -0.54$, $p = .59$, $\Delta R^2 = .00$).

Taken together, these results provide strong support for the assumption that an expository hypertext with topical and rhetorical signals can compensate for deficits in reading skill. Compared to learning with a typical linear text where basic reading skill was an important predictor of learning outcomes, learning with a hypertext that contained topical and rhetorical signals completely alleviated negative effects of poorly routinized reading comprehension processes, yielding overall good learning outcomes for readers on all levels of reading skill. This pattern of effects was found not only for the amount of knowledge that learners acquired, but also for the two more qualitative indicators knowledge focusing and degree of integration. These two aspects of learning outcomes correspond to the strategies of information selection and integration that are pointed out by the cognitive theory of multimedia learning (Mautone & Mayer, 2001). Thus, the results provide indirect support for the idea that the signals provided by the hypertext facilitated the application of these strategies.

However, the conclusions that may be drawn from Experiment 1 are also limited in two important respects. First, the hypertext and the linear text compared in this study differed not only in the hypertext-specific signals highlighted in our hypotheses but also in a number of other respects, most importantly the medium in which the texts were presented (computer-based vs. print). Second, since no on-line measures were obtained in Experiment 1, an interpretation referring to the processes underlying the effects of signals on learning outcomes remains speculative. To overcome these limitations, we conducted a second experiment with a design that extended that of Experiment 1 in several ways.

Experiment 2

The first goal of Experiment 2 was to provide stronger evidence for the assumption that the hypertext-specific topical and rhetorical signals were causally relevant for the superior learning outcomes of participants learning with a hypertext compared to those learning with a linear text. For this purpose, we included not only the linear text and the hypertext used in Experiment 1, but also a hypertext that lacked a graphical overview of the general text structure and contained only a greatly reduced number of hyperlinks. For participants learning with this restricted hypertext version, we hypothesized the same pattern of effects as for the linear text version. In particular, we expected a positive relationship of reading skill and learning outcomes in participants learning with the linear text or the restricted hypertext, and we expected this relationship to be weaker or nonexistent in participants learning with the version of the hypertext that contained the full set of hypertext-specific topical and rhetorical signals. In addition, we expected that in learners with a low level of reading skill, learning outcomes would be better after learning with the hypertext with topical and rhetorical signals than after learning with the restricted hypertext or the linear text. Learners with a high level of reading skill, in contrast, were expected to learn well with all three text versions. If the pattern of effects of reading skills indeed turned out to be the same for the restricted hypertext version and the linear text, this could be regarded as strong evidence for the assumed causal role of hypertext-specific signals in compensating for deficits in reading skill.

The second goal of Experiment 2 was to augment the analysis of learning outcomes with an analysis of navigational behavior of participants learning with the hypertext that contained hypertext-specific topical and rhetorical signals, compared to participants learning with the restricted hypertext version that contained a greatly reduced amount of these signals. To obtain information on quantitative aspects of the learning process, we looked at the total number of page visits and the number of visits to task-relevant pages. Since the number of

visits to task-relevant pages should be related to strategies for selecting and organizing the learning contents, we expected this number (but not the number of page visits in general) to be larger in the hypertext that contained signals than in the restricted hypertext version. Likewise, we assumed that the number of visits to task-relevant pages would be positively related to learning outcomes.

In addition, we considered two indicators that are informative with respect to the quality of navigational decisions. The number of linear sequences within multiple-page nodes indicates how thoroughly learners study the presented contents. Consequently, this variable has been found to be positively associated with learning outcomes (Niederhauser, Reynolds, Salmen, & Skomolski, 2000; Richter, Naumann, & Noller, 2003). We expected the number of linear sequences to be larger in participants learning with the hypertext that contained topical and rhetorical signals because the presence of signals would help participants to organize and select task-relevant pages efficiently, thus leaving them more time to study the relevant contents. Conversely, the number of backtracks, i.e. regressions to pages visited in the previous step, may be regarded as an indicator of the amount of trial-and-error scanning of pages for relevant information (McEneaney, 2001; Richter et al., 2003). We expected this number to be larger in participants learning with the restricted hypertext because the relative lack of signals would prompt learners to rely on a strategy of trial-and-error scanning. At the same time, we expected a positive relation between the number of backtracks and reading skill in the restricted hypertext condition, because trial-and-error scanning of pages should be easier for subjects with highly routinized basic reading processes.

Method

Participants

Forty-six undergraduate students of psychology (74% women) from the University of Cologne and the University of Heidelberg participated in Experiment 2. The mean age was

24.1 years ($SD = 5.0$). Participants were paid approximately \$65 or received credit for research participation. Twenty-nine participants were in the first year of studies, the remaining 17 participants were in the second year of studies. Twenty-four participants had taken or were currently taking a course on the psychology of perception, including lessons on visual perception. Participants were recruited by postings on the psychology department's message boards and mailing list.

Text material

We used the same linear text and the same hypertext on visual perception as in Experiment 1. In addition, we constructed a restricted version of the hypertext from which the main signals in the original hypertext were removed, but that still provided learners with some basic navigational features. In particular, the restricted hypertext lacked the introductory page that served as a topical overview. Correspondingly, the small browser at the bottom left of each page mimicking the introductory page in the original hypertext was not present. Moreover, the restricted hypertext lacked 67% of the hyperlinks contained in the original hypertext. Specifically, the hyperlinks at the end of each node linking conceptually related nodes were removed, while all embedded hyperlinks and all hyperlinks placed on overview pages were left intact. Also, the restricted hypertext did still provide learners with the graphical browser called gallery, the graphical browsers depicting the contents of the nodes within each section, the dynamic table of contents, the backtrack function, and the history list.

Procedure and task

As in Experiment 1, prior knowledge and reading skill were assessed two weeks before the experimental session. Participants were randomly assigned to either the linear text, the hypertext or the restricted hypertext condition. The experimental sessions again comprised an introductory phase, a learning phase and a writing phase.

Introductory phase. The introductory phase was exactly the same as in Experiment 1 for both the participants in the hypertext and those in the restricted hypertext conditions (none of the hypertext's navigational functions that were demonstrated in the introductory phase were removed in the restricted hypertext). The introductory phase for participants in the linear text condition was also the same as in Experiment 1.

Learning phase. For the learning phase, participants were given three different tasks. Specifically, participants were asked to study for three shorter essays on "Important theories in visual perception", "Important studies on the perception of space", and "Theories and experiments on the perception of color". Again, the essays should be composed in a way that other students could use these essays to prepare for an exam. As in Experiment 1, the learning tasks required to search for information from various parts of the hypertext and integrate it into a coherent representation of the subject matter. Subjects were given one hour to study for each of the three essays. The order in which the participants were asked to engage in each of the tasks was counterbalanced within each condition.

Writing phase. After a one-hour break participants completed the three requested essay-writing tasks in the order in which they had studied for them. Again, they were allowed to use the notes they had taken during the learning phase but had no access to the text. Participants wrote on a PC using *Word for Windows*. The writing phase lasted for three hours. After one hour of working on an essay, participants were asked to switch to the next essay.

Measured variables

Learning outcomes. Learning outcomes were assessed by a content analysis of the essays produced by participants during the writing phase (pooled across all three essays). The essays were segmented into idea units and analogous coding schemes as in Experiment 1 were used to derive counts of the total number of idea units ($M = 204.83$, $SD = 78.92$), the number of task-related idea units ($M = 134.00$, $SD = 60.09$), and the number of idea units that

contained an inference ($M = 28.95$, $SD = 16.46$). As in Experiment 1, we applied a logarithmic transformation to the total number of idea units to determine the first dependent variable *amount of knowledge*. The second dependent variable *knowledge focusing* was computed by dividing the logarithmically transformed number of task-related idea units by the logarithmically transformed total number of idea units. Similarly, the third dependent variable *degree of integration* was computed by dividing the logarithmically transformed number of idea units with inferences by the logarithmically transformed total number of idea units. The second and third dependent variable were checked for cases with irregular values by regressing the number of task-related idea units and the number of idea units with inferences on the total number of idea units and inspecting the distribution of residuals for outliers. For both variables, one irregular case was identified by this procedure. The irregular cases had studentized residuals larger than three and were significant according to the procedure suggested by Beckman and Cook (1983). For these two cases, we used the predicted values from the regression on the total number of idea units to substitute the original number of task-related idea units or the original number of idea units with inferences, respectively.

Reading skill. As in Experiment 1, reading skill was assessed by the subtest *sentence verification* of the instrument ELVES (Richter & van Holt, 2005). In the present sample, the test had an internal consistency (Cronbach's α) of .83.

Prior knowledge. Prior knowledge was assessed by the same multiple choice test that had been used in Experiment 1. In the present sample, the scale had an internal consistency (Cronbach's α) of .83 with a mean item difficulty of .43.

Navigational behavior. Throughout the learning session, page visits were recorded for each participant who learned with the hypertext or the restricted hypertext. These data were then processed using LOGPAT (Logfile Pattern Analysis, Richter et al., 2003), a tool for the

generation of indices describing the navigational behavior of individual hypertext users. Four indices, two based on frequencies of page visits (atomistic measures) and two based on frequencies of navigational patterns (sequential measures), were computed. These four indices were selected because they represent elementary measures that may be assumed to tap complementary aspects of navigational behavior.

(1) As an indicator of the overall quantity of contents that participants looked at, we counted the *total number of page visits* in each participant's navigational path.

(2) As an indicator of the amount of task-focused navigational behavior, we counted the *number of visits to task-relevant pages*, i.e. content pages with information directly relevant for accomplishing the particular learning task that participants had worked on (theories of visual perception, studies on the perception of form, or theories and experiments on the perception of color). The number of task-relevant pages in the hypertext materials was similar for all three tasks, amounting to 31 (theories of visual perception), 29 (studies on the perception of form) and 27 (theories and experiments on the perception of colour), respectively.

(3) As an indicator of how thoroughly contents were studied, we counted the *number of two-step linear sequences* ($\text{page}_{A1} - \text{page}_{A2}$) within one node in each participant's navigational path. In the literature on learning with hypertext, the occurrence of linear sequences is regarded as an indicator of thorough study behavior and has repeatedly been found to be positively correlated with learning outcomes (Niederhauser et al., 2000; Richter et al., 2003; Richter, Naumann, Brunner, & Christmann, 2005). The more frequently participants studied more than one page of longer nodes in the hypertext (as opposed to quickly jumping from one node to another), the higher the number of two-step linear sequences in their navigational paths. We chose two-step linear sequences as the focal event because it is the most elementary and most frequent type of linear sequences. The frequencies of two-step linear

sequences usually correlate strongly with the frequencies of linear sequences with three or more steps (Richter et al., 2003).

(4) As an indicator of trial-and-error scanning of content pages, we counted the number of *three-step backtrack sequences* ($\text{page}_A - \text{page}_B - \text{page}_A$) in each participant's navigational path. Frequent backtracks usually occur when users explore the hypertext without following a specific search strategy. They may be a sign of disorientation (Berendt & Brenstein, 2002) and are often negatively associated with learning outcomes (McEneaney, 2001; Richter et al., 2003, 2005). Again, we chose three-step backtrack sequences as the focal event because these sequences represent the most elementary and most frequent type of backtracks.

Results and Discussion

Similar to Experiment 1, we conducted separate multiple regression analyses with interaction terms for each of the three learning outcome measures as dependent variables and text structure (hypertext vs. restricted hypertext vs. linear text), reading skill, prior knowledge, and interactions of text structure and reading skill as predictor variables. Prior knowledge and reading skill were entered as z -standardized variables. Text structure was entered in the form of two dummy-coded predictor variables with the (unrestricted) hypertext as reference group. The first predictor captured the difference between the hypertext condition (coded with 0) and the linear text condition (coded with 1), the second predictor the difference between the hypertext condition (coded with 0) and the restricted hypertext condition (coded with 1). Accordingly, the interaction of text structure and reading skill was entered in form of two interaction terms, the first one capturing the difference in the regressions slopes between the hypertext condition and the linear text condition and the second one capturing the difference in the regression slopes between the hypertext condition and the restricted hypertext condition. In moderated regression designs, however, dummy coding leads to estimates for the effect of the continuous predictor that do not represent its

main effect, but rather its simple slope within the reference group. For this reason, we additionally applied a contrast-coding scheme (using Helmert contrasts) to estimate the main effect of reading skill. Univariate descriptive statistics and correlations for all variables in Experiment 2 are reported in Table 4. Univariate descriptive statistics for all variables (unstandardized and untransformed) in each experimental condition are reported in Table 2.

Effects of Text Structure and Reading Skill on Learning Outcomes

Equivalence of experimental groups and distribution of residuals. Prior knowledge did not differ significantly between the linear text condition ($M = 10.29$, $SE_M = 1.67$) on the one hand and the hypertext condition ($M = 13.00$, $SE_M = 1.06$), $t(29) = 1.39$, $p > .10$ (two-tailed), $d = 0.45$, or the restricted hypertext condition ($M = 8.50$, $SE_M = 0.97$) on the other hand, $t(28) = 0.91$, $p > .10$ (two-tailed), $d = 0.29$. The difference in prior knowledge between the hypertext condition and the restricted hypertext condition was significant, $t(29) = 3.10$, $p < .01$ (two-tailed), $d = 0.99$. However, prior knowledge was controlled for in all analyses concerning learning outcomes. For this reason, the lack of equivalence of the experimental conditions in this variable was unlikely to distort the validity of results. Reading skill did not differ between the linear text condition ($M = 18.45$, $SE_M = 0.94$), the hypertext condition ($M = 18.06$, $SE_M = 1.09$), and the restricted hypertext condition ($M = 19.96$, $SE_M = 1.49$), for all comparisons $t < 1.10$, $p > .10$ (two-tailed), $d < 0.42$. Residuals were distributed normally in the regression model for degree of integration ($K-S-Z < .11$, $p > .19$) and displayed no heteroscedasticity when plotted against the predicted values. In the model for knowledge focusing, one extremely low value in the criterion variable caused a residual distribution that differed from a normal distribution ($K-S-Z = .13$, $p < .10$). Removal of the outlier from the model produced normally distributed residuals ($K-S-Z = .09$, $p > .20$).

Amount of knowledge. The results of the regression model for amount of knowledge are summarized in Table 5 (left columns). There was no main effect for the control variable prior

knowledge. Reading skill had a large positive average effect ($B = 0.17$, $SE_B = 0.04$, $t(39) = 4.52$, $p < .001$, $\Delta R^2 = .14$), as revealed by an additional analysis based on contrast coding. Moreover, both comparisons between text structure conditions were significant. Participants in the hypertext condition demonstrated an overall higher amount of knowledge compared to participants both in the linear text condition and the restricted hypertext condition. Both of these contrasts also had significant and medium-sized interaction effects with reading skill. Simple slope analyses revealed that as predicted, reading skill had a large positive effect in the linear text condition ($B = 0.32$, $SE_B = 0.08$, $t(39) = 4.10$, $p < .001$, $\Delta R^2 = .11$) and in the restricted hypertext condition ($B = 0.20$, $SE_B = 0.05$, $t(39) = 3.92$, $p < .001$, $\Delta R^2 = .11$) but no effect in the hypertext condition (Table 5, third row). At a low level of reading skill (one standard deviation below the mean), the amount of knowledge of participants in the hypertext condition was much higher than that of participants in the linear text condition ($B = -0.97$, $SE_B = 0.12$, $t(39) = -7.90$, $p < .001$, $\Delta R^2 = .44$) or of participants in the restricted hypertext condition ($B = -0.65$, $SE_B = 0.12$, $t(39) = -5.28$, $p < .001$, $\Delta R^2 = .19$). At a high level of reading skill (one standard deviation above the mean), in contrast, participants in the hypertext condition still performed better than participants in the linear text condition ($B = -0.36$, $SE_B = 0.15$, $t(39) = -2.40$, $p < .05$, $\Delta R^2 = .04$) and participants in the restricted hypertext condition ($B = -0.26$, $SE_B = 0.13$, $t(39) = -2.03$, $p < .05$, $\Delta R^2 = .03$) but these differences were considerably smaller.

Knowledge focusing. The results of the regression model for knowledge focusing are summarized in Table 5 (middle columns). There was a medium-sized effect for the control variable prior knowledge. An additional analysis based on contrast codes revealed a medium-sized average effect for reading skill ($B = 0.01$, $SE_B = 0.01$, $t(38) = 2.30$, $p < .01$, $\Delta R^2 = .09$). None of the comparisons of text structure conditions were significant. There was a medium-sized interaction between reading skill and the contrast of the restricted hypertext and the

hypertext conditions whereas the interaction between reading skill and the contrast of the linear text and hypertext conditions failed to reach significance. Simple slope analyses revealed that as expected, reading skill had a large effect in the restricted hypertext condition ($B = 0.03$, $SE_B = 0.01$, $t(39) = 3.22$, $p < .01$, $\Delta R^2 = .18$) but no effect in the hypertext condition (Table 5). Contrary to our expectations and the results of Experiment 1, however, the effect of reading skill in the linear text condition also failed to reach significance ($B = 0.02$, $SE_B = 0.01$, $t(38) = 1.49$, $p = .14$, $\Delta R^2 = .04$). At a low level of reading skill (one standard deviation below the mean), participants in the hypertext condition did not differ in knowledge focusing from participants in the linear text condition ($B = -0.01$, $SE_B = 0.02$, $t(39) = -0.53$, $p = .53$, $\Delta R^2 = .00$) or from participants in the restricted hypertext condition ($B = -0.00$, $SE_B = 0.02$, $t(39) = -0.20$, $p = .84$, $\Delta R^2 = .00$). At a high level of reading skill (one standard deviation above the mean), participants in the hypertext condition also did not differ significantly from participants in the linear text condition ($B = 0.03$, $SE_B = 0.02$, $t(39) = 1.22$, $p = .23$, $\Delta R^2 = .02$) but they performed slightly worse than participants in the restricted hypertext condition ($B = 0.03$, $SE_B = 0.01$, $t(39) = 2.07$, $p < .05$, $\Delta R^2 = .07$).

Degree of integration. The results of the regression model for degree of integration are summarized in Table 5 (right columns). An additional analysis based on contrast codes revealed a medium-sized average effect for reading skill ($B = 0.04$, $SE_B = 0.02$, $t(39) = 2.64$, $p < .05$, $\Delta R^2 = .11$). The comparison of text restricted hypertext condition with the hypertext condition was significant. Overall, participants in the hypertext condition demonstrated a higher degree of integration than participants in the restricted hypertext condition. In addition, both terms capturing interactions of text structure with reading skill were significant. In simple slope analyses, reading skill had a medium-sized positive effect in the linear text condition ($B = 0.06$, $SE_B = 0.03$, $t(39) = 2.06$, $p < .05$, $\Delta R^2 = .07$) and a large positive effect in the restricted hypertext condition ($B = 0.07$, $SE_B = 0.02$, $t(39) = 3.60$,

$p < .001$, $\Delta R^2 = .20$) but no effect in the hypertext condition ($B = -0.02$, $SE_B = 0.03$, $t(39) = -0.55$, $p = .58$, $\Delta R^2 = .00$). At a low level of reading skill (one standard deviation below the mean), participants in the hypertext condition demonstrated a higher degree of integration than participants in the linear text condition ($B = -0.10$, $SE_B = 0.05$, $t(39) = -2.03$, $p < .05$, $\Delta R^2 = .06$) and a much higher degree of integration than participants in the restricted hypertext condition ($B = -0.19$, $SE_B = 0.05$, $t(39) = -3.82$, $p < .001$, $\Delta R^2 = .23$). At a high level of reading skill (one standard deviation above the mean), in contrast, participants in the hypertext condition did not differ in their degree of integration from participants in the linear text condition ($B = 0.06$, $SE_B = 0.06$, $t(39) = 0.97$, $p = .34$, $\Delta R^2 = .01$) or from participants in the restricted hypertext condition ($B = -0.01$, $SE_B = 0.05$, $t(39) = -0.21$, $p = .84$, $\Delta R^2 = .00$).

With the exception of the results for knowledge focusing, the results of Experiment 2 closely replicated those of Experiment 1. The hypertext that contained a large amount of hypertext-specific topical and rhetorical signals enabled learners with a low level of reading skill to achieve learning outcomes that are as good as those of learners with a high level of reading skill. Most importantly, however, Experiment 2 demonstrated that in learning with a linear text or a hypertext that lacked most of these signals, reading skill had a strong positive effect, and learners with a low level of reading skill performed much worse than their counterparts who learned with the non-restricted hypertext. The strongly parallel results for linear text and hypertext with little signaling underscore that hypertext-specific signals are indeed critical for compensating for low reading skill.

However, we found only incomplete support for the hypothesized interaction effects of text structure and reading skill on knowledge focusing. Reading skill had a positive effect in the restricted hypertext condition and no effect in the hypertext condition but none of the other parts of the predicted pattern of interactions emerged. One likely cause for the failure to support our hypotheses for knowledge focusing is the limited range of the variance of this

variable: Compared to Experiment 1, participants exhibited an overall high degree of knowledge focusing, with very little interindividual variation (Table 4, Figure 1e).

Apparently, the three precise essay tasks that participants had to prepare for in Experiment 2 made it easier for all participants to focus on relevant text contents, compared to the more global essay task used in Experiment 1.

Finally, we need to note that the groups of participants that received the hypertext and the restricted hypertext, respectively, were not perfectly balanced with respect to prior knowledge, as indicated by the small correlation of prior knowledge and the dummy variable that contrasts both conditions (Table 4, third row). Although we controlled for prior knowledge in all regression models, there remains a slight possibility that the parameter estimates relevant to our hypotheses were influenced by the confound of text structure and prior knowledge.

Relationships of Navigational Behavior With Reading Skill and Learning Outcomes

Differences between hypertext and restricted hypertext. The total number of page visits in the participants' navigational paths did not differ between the hypertext and restricted hypertext conditions (hypertext: $M = 176.56$, $SE_M = 12.20$; restricted hypertext: $M = 182.80$, $SE_M = 17.77$, $t(29) = -0.29$, $p > .05$). Contrary to our expectations, the number of visits to task-relevant pages did not differ between the hypertext and the restricted hypertext condition either (hypertext: $M = 41.13$, $SE_M = 5.18$; restricted hypertext: $M = 34.60$, $SE_M = 6.29$, $t(29) = 0.32$, $p > .05$). Both of the indices based on navigational patterns, however, differed markedly and in the expected direction between the hypertext and restricted hypertext conditions. The navigational paths of participants in the hypertext condition contained more linear sequences than the navigational paths of participants in the restricted hypertext condition (hypertext: $M = 42.44$, $SE_M = 2.95$; restricted hypertext: $M = 25.60$, $SE_M = 2.86$, $t(29) = 4.09$, $p < .001$, $d = 1.47$), whereas there were more backtracks in the restricted hypertext condition (hypertext: M

= 40.44, $SE_M = 2.41$; restricted hypertext: $M = 55.73$, $SE_M = 5.07$, $t(29) = -2.73$, $p < .05$, $d = 0.99$). These differences indicate that participants learning with the hypertext that contained more hypertext-specific signals showed a more thorough study behavior. They also had to rely less on trial-and-error scanning of pages than participants in the restricted hypertext condition. Apparently, the higher amount of signaling in the unrestricted hypertext supported learners in selecting and organizing the text contents.

Relationships of navigational behavior with learning outcomes. As predicted, the number of visits to task-relevant pages and the number of linear sequences had substantial positive correlations with learning outcomes, with the exception of the relationship of linear sequences and knowledge focusing (see Table 4, cells defined by rows 9 to 11 and columns 6 and 7). These results are consistent with the interpretation that these indices reflect the application of strategies for organizing and selecting the learning materials. Neither the total number of page visits nor the number of backtracks were consistently related to learning outcomes (Table 4, cells defined by rows 9 to 11 and columns 5 and 8).

Relationships of navigational behavior with reading skill. Apart from the number of linear sequences, all navigational indices taken into account had substantial positive correlations with reading skill (Table 4, cells defined by rows 5 to 8 and column 4). The magnitude of these relationships, however, differed between text structure conditions, with the correlations being stronger in the restricted hypertext condition. Although the design of Experiment 2 does not provide sufficient power to test these differences statistically, the overall pattern of results coheres well with the differential relationships found for reading skill and learning outcomes and the corresponding assumption of a compensatory function of reading skill and hypertext-specific signals. For the total number of page visits, there was a correlation of .51 in the restricted hypertext condition ($p = .05$) but a smaller correlation of .36 in the hypertext condition ($p = .17$). Similarly, the correlation of number of linear

sequences with reading skill was .46 in the restricted hypertext condition ($p < .10$) but only .19 ($p = .24$) in the hypertext condition, and the correlation of number of backtracks with reading skill was .56 ($p < .05$) in the restricted hypertext condition but approached zero in the hypertext condition ($r = -.05$, $p = .85$). In sum, reading skill had consistent and strong positive correlations with all quantitative indices of navigational behavior in the restricted hypertext condition, but only inconsistent and overall weaker correlations in the hypertext condition.

General Discussion

The aim of the present paper was to test the hypothesis that a hypertext that contains hypertext-specific signals can compensate for deficits in reading skill, i.e. badly routinized basic processes of reading comprehension. Two experiments were conducted that provided evidence for this assumption. In both experiments, deficits in reading skill lead to a marked decline of learning outcomes when learners studied with a typical linear text. When learners studied with a hypertext that contained hypertext-specific signals, in contrast, deficits in reading skill had no deteriorating effect on qualitative and quantitative aspects of learning outcomes. In particular, the hypertext containing signals positively influenced the amount of knowledge that learners with badly routinized reading skills acquired, their degree of focusing on a given learning task, and the degree of integration of text contents with prior knowledge. For learners with highly routinized reading comprehension processes, it did not make a difference whether they learned with a linear text or a hypertext containing signals. Experiment 2 demonstrated that these compensatory effects were indeed due to the presence of hypertext-specific signals: In learning with a hypertext from which these signals were removed, reading skill had positive effects on learning outcomes that paralleled the effects of reading skill in learning with a linear text. Moreover, the navigational data obtained in Experiment 2 provide some on-line evidence that the presence of signals in a hypertext

enabled learners to select and organize contents more efficiently. Without the support provided by these signals, learners had to rely on less efficient strategies such as the trial-and-error scanning of pages for relevant contents.

These results are consistent with the ideas that signals facilitate comprehension processes directed at establishing the macrostructure of a text (van Dijk & Kintsch, 1983) and that they promote the organization, selection, and integration of the to-be-learned information. Apparently, hypertext-specific signals are particularly helpful for learners with badly routinized reading comprehension processes. These results partially opposes the traditional and widespread view that expository hypertexts invariably make high demands on learners' cognitive abilities (e.g., Foltz, 1996). On the contrary, when hypertexts are equipped with certain types of hypertext-specific signals, they may even provide a remedy for deficits in one important generalized cognitive ability, namely basic reading skill. It is important to note that the signals that were investigated in the present studies represent textual devices that are typical for hypertexts but that would be hard to implement in linear texts.

Why are hypertext-specific signals such as navigable topical overviews and hyperlinks so effective in helping poor readers to build a rich and coherent representation of the to-be-learned material? For topical overviews, it seems plausible to assume that this type of signaling device supports learning by providing clues to the thematic structure of the learning material. Accordingly, topical overviews may be assumed to promote strategies directed at organizing the contents of the learning material into a macrostructurally coherent representation by highlighting the main points and their thematic relationships. By the same means, they also promote strategies directed at selecting relevant contents. Because of their dual function as signaling device and navigational aid, hypertext-specific topical overviews simplify the application of these strategies and make them less resource demanding, even compared to conventional signaling devices such as summaries or tables of contents that also

have the potential to take cognitive load away from the learner. For example, the application of selection strategies is facilitated when learners can easily check out the contents of a page that is linked to a main point in a topical overview. They can also go back frequently to the topical overview between visits to content pages. In this way, even poor readers are able to create efficient retrieval structures, with strong associations between elements of the macrostructure and more detailed information.

Hyperlinks may contribute to a horizontally interconnected representation by providing clues to conceptual relationships between different aspects of the learning material. In principle, hyperlinks are suited to signal all kinds of conceptual relationships, from superordinate-subordinate and part-whole relations over definitions of concepts to temporal, causal and explanatory relations. In order to fulfill this function, the relationship between the two pages connected by the hyperlink must be made explicit to the learner (either by a verbal description or by a typed link, Hammwöhner & Kuhlen, 1994). In this case, hyperlinks may be expected to promote strategies directed at organizing relevant contents, similar to conventional signaling devices such as cross-references or the explication of rhetorical relationships. However, as navigable cross-references they differ from conventional signaling devices in that they facilitate immediate exploration of the signaled relationship. Learners can explore the conceptual relationship suggested by a hyperlink with relatively little cognitive effort. As a consequence, even learners with poorly routinized reading skills may be able to understand the signaled relationship. They may even be able to devote more resources to the integration of text information with their prior knowledge. In sum, hypertext-specific signaling devices may be particularly effective because they are signals and navigational aids at the same time. Generally speaking, hypertext-specific signals might be beneficial in two ways that supplement each other, making hypertexts more suitable to learners with a lower level of

abilities: They might have the potential to attenuate the demands on learners' abilities while providing them with more degrees of freedom for self-regulated learning.

At this point these ideas are still largely speculative and call for more empirical evidence. Thus, a fruitful direction for future research would be to take a closer look at the macrostructural processes that hypertext-specific signals induce in learners on different levels of reading skill. Because of the assumed strategic character of these processes (Mautone & Mayer, 2001), the use of explicit techniques such as think-aloud methods would represent a useful complement to implicit on-line measures such as log-file data, reading times or eye-tracking data for assessing macrostructural processes (for a similar argument, cp. Kaakinen & Hyönä, 2005). We would expect such a study to demonstrate that the amount of macrostructural processing mediates aptitude-interaction effects of reading skill and signaling on learning outcomes (mediated moderation, Muller, Judd, & Yzerbyt, 2005).

The theoretical interpretation advocated here raises two further questions that could be addressed in future studies. The first question pertains to the distinctiveness of hypertext-specific signals. Although it is plausible to assume that the hypertext-specific signals investigated in this study were particularly effective, other types of signals might be able to fulfill similar compensatory functions, albeit to a lesser extent. Experiments that allow systematic investigations of the way in which different types of signals interact with reading skill would be suitable to clarify this issue. The second question regards the role of working memory capacity (Just & Carpenter, 1992) in explaining the effects of hypertext-specific signals. Parts of our theoretical argument rely on the assumption that hypertext-specific signals are particularly effective for learners with inefficient reading comprehension processes because the working memory resources that these learners can spend on macrostructural processing are limited. More research is needed that addresses the validity of

this interpretation more directly, for example by including measures of working memory capacity such as the reading span (Daneman & Carpenter, 1981).

Finally, it is important to note two potential limitations that stem from the particular methodological features of the present experiments. Both the learning tasks and the comprehension measures that we used in these experiments were chosen to approximate everyday self-regulated learning in academic settings as closely as possible. Although care was taken to maintain a maximum of experimental control and objectivity, the tasks are far more complex than the tasks that have typically been used in cognitive research on signaling. For this reason, it would be desirable to replicate the present experiments with shorter texts and less complex tasks as they are typically used in signaling research (such as free recall or recognition methods). Another potential limitation is that both experiments used texts on one particular topic instead of multiple texts. Strictly speaking, it remains an open question whether the present results generalize to texts on other topics.

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Table 1

Means, Standard Deviations, and Correlations of all Variables in Experiment 1

	<i>M</i>	<i>SD</i>	Correlations				
			1	2	3	4	5
<i>Predictor variables</i>							
1 Hypertext vs. linear text ^a	0.00	0.50					
2 Prior knowledge ^b	8.95	5.04	.17				
3 Reading skill	18.62	4.47	.07	.14			
<i>Learning outcomes</i>							
4 Amount of knowledge (log)	5.18	0.36	.21*	.16	.28*		
5 Knowledge focussing	0.72	0.16	.26**	.00	.31**	.26*	
6 Degree of integration	0.52	0.15	.15	.27*	.32**	.00	-.08

Note. $N = 84$. ^a Contrast-coded, hypertext = 0.5, linear text = -0.5. ^b $W: 0-24$

* $p < .05$, ** $p < .01$, *** $p < .001$ (two-tailed).

Table 2

Means (and Standard Deviations) of all Variables (Untransformed and Non-standardized) in the Experimental Conditions of Experiments 1 and 2

	Experiment 1		Experiment 2		
	Linear Text	Hypertext	Linear Text	Hypertext	Restricted Hypertext
	<i>M (SD)</i>				
Amount of knowledge	179.88 (71.21)	197.10 (46.19)	144.27 (55.69)	277.19 (54.91)	188.20 (58.98)
Number of task-related idea units	45.55 (31.32)	62.90 (34.92)	90.47 (33.49)	173.81 (50.94)	135.07 (62.15)
Number of idea units with inferences	15.71 (12.18)	20.10 (12.82)	25.93 (15.58)	38.50 (16.33)	21.73 (13.14)
Total number of page visits	--	--	--	176.56 (48.80)	182.80 (68.84)
Number of visits to task-relevant pages	--	--	--	41.13 (20.71)	34.60 (24.37)
Number of linear sequences	--	--	--	42.44 (11.80)	25.60 (11.09)
Number of backtracks	--	--	--	40.44 (9.63)	55.73 (19.63)
Prior knowledge	8.10 (5.08)	9.81 (4.92)	10.29 (6.45)	13.00 (4.27)	8.53 (3.76)
Reading skill	18.31 (4.21)	18.94 (4.75)	18.45 (3.36)	18.07 (4.07)	19.96 (5.59)

Table 3

Summary of Moderated Regression Analyses for the Effects of Text Structure (Hypertext vs. Linear Text) and Reading Skill on Learning Outcomes in Experiment 1

	Amount of knowledge				Knowledge focusing				Degree of integration			
	<i>B</i>	<i>SE_B</i>	<i>t</i> (79)	ΔR^2	<i>B</i>	<i>SE_B</i>	<i>t</i> (79)	ΔR^2	<i>B</i>	<i>SE_B</i>	<i>t</i> (79)	ΔR^2
Intercept (<i>B</i> ₀)	5.19	0.04			0.72	0.02			0.52	0.08		
Prior knowledge ^a	0.00	0.04	-0.01	.00	-0.03	0.02	-1.76 ⁺	.03	0.02	0.02	1.32	.02
Reading skill ^a	0.11	0.04	2.89**	.09	0.06	0.02	3.51***	.12	0.05	0.02	3.01**	.09
Text structure ^b	0.13	0.07	1.79 ⁺	.03	0.09	0.03	2.67**	.07	0.03	0.03	1.03	.01
Text structure × Reading skill	-0.20	0.08	-2.49**	.06	-0.10	0.02	-2.92**	.08	-0.06	0.03	-1.68 ⁺	.03
Model fit	$R^2 = .19, R^2_{\text{corr}} = .15$				$R^2 = .24, R^2_{\text{corr}} = .20$				$R^2 = .19, R^2_{\text{corr}} = .15$			
Omnibus test	$F(4,79) = 4.53**$				$F(4,79) = 6.19***$				$F(4,79) = 4.67**$			

Note. ^a *z*-standardized, ^b Contrast-coded, hypertext = 0.5, linear text = -0.5.

⁺ $p < .10$, * $p < .05$, ** $p < .01$, *** $p < .001$ (two-tailed).

Table 4

Means, Standard Deviations, and Correlations of all Variables in Experiment 2

	<i>M</i>	<i>SD</i>	Correlations									
			1	2	3	4	5	6	7	8	9	10
<i>Predictor variables</i> ^a												
1 Linear text vs. hypertext ^b	0.33	0.47										
2 Restricted hypertext vs. hypertext ^c	0.33	0.47	(-.50)									
3 Prior knowledge ^d	10.67	5.24	-.05	-.29*								
4 Reading skill	18.82	4.46	-.06	.18	-.02							
<i>Navigational behavior</i> ^e												
5 Total number of pages	179.58	58.41	--	.05	-.07	.46**						
6 Number of task-relevant pages	37.97	22.42	--	-.15	.37*	.43*	.44*					
7 Number of linear sequences	34.29	14.15	--	-.60***	.36*	.15	.29	.08				
8 Number of backtracks	47.84	16.93	--	.46***	-.34*	.43*	.71***	.25	-.24			
<i>Learning outcomes</i> ^a												
9 Amount of knowledge (log.)	5.25	0.41	-.57***	-.09	.17	.38**	.08	.30*	.40*	-.10		
10 Knowledge focusing	0.92	0.05	-.05	.09	.25	.37*	.05	.52**	-.01	.23	.21	
11 Degree of integration	0.60	0.11	.05	-.33*	.18	.35*	.35*	.39*	.51**	.12	.38	.12

Note. ^a $N = 46$. ^b Dummy-coded, linear text = 1, hypertext = 0. ^c Dummy-coded, restricted hypertext = 1, hypertext = 0. ^d $W: 0-24$. ^e $n = 30$.

* $p < .05$, ** $p < .01$, *** $p < .001$.

Table 5

Summary of Moderated Regression Analyses for the Effects of Text Structure (Hypertext vs. Restricted Hypertext vs. Linear Text) and Reading Skill on Learning Outcomes in Experiment 2

	Amount of knowledge				Knowledge focusing				Degree of integration			
	<i>B</i>	<i>SE_B</i>	<i>t</i> (39)	ΔR^2	<i>B</i>	<i>SE_B</i>	<i>t</i> (38)	ΔR^2	<i>B</i>	<i>SE_B</i>	<i>t</i> (39)	ΔR^2
Intercept (<i>B</i> ₀)	5.61	0.06			0.91	0.01			0.64	0.02		
Prior knowledge ^a	0.01	0.04	0.27	.00	0.01	0.01	2.17**	.08	0.01	0.01	0.63	.00
Reading skill ^a	0.01	0.07	0.07	.00	-0.00	0.01	-0.21	.00	-0.02	0.03	-0.55	.00
Linear text vs. Hypertext ^b	-0.36	0.15	-2.40**	.41	0.01	0.01	0.59	.01	-0.02	0.03	-0.62	.00
Restricted hypertext vs. Hypertext ^c	-0.26	0.13	-2.03*	.17	0.02	0.01	1.67	.10	-0.10	0.04	-2.73**	.11
(Linear text vs. Hypertext) × Reading skill	0.31	0.11	2.94**	.06	0.02	0.02	1.23	.03	0.08	0.04	1.87 ⁺	.05
(Restricted hypertext vs. Hypertext) × Reading skill	0.20	0.09	2.25*	.04	0.03	0.01	2.07*	.06	0.09	0.03	2.57*	.10
Model fit	$R^2 = .73, R^2_{\text{corr}} = .69$				$R^2 = .35, R^2_{\text{corr}} = .25$				$R^2 = .40, R^2_{\text{corr}} = .31$			
Omnibus test	$F(6,39) = 17.38***$				$F(6,38) = 3.41**$				$F(6,39) = 4.30**$			

Note. Due to dummy coding and the inclusion of text structure × reading skill interaction terms, the regression coefficients for reading skill represent simple slopes in the hypertext condition. See text for estimates of the main effects of reading skill.

^a z-standardized, ^b Dummy-coded, linear text = 1, hypertext = 0, ^c Dummy-coded, restricted hypertext = 1, hypertext = 0.

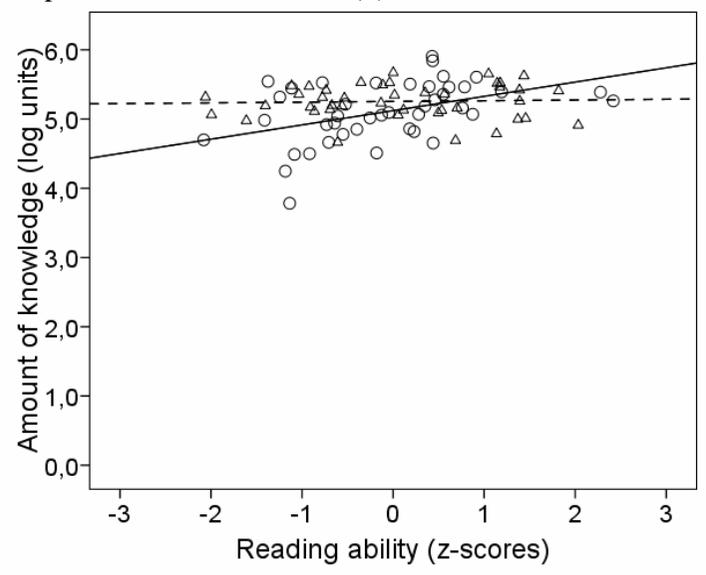
⁺ $p < .10$, * $p < .05$, ** $p < .01$, *** $p < .001$ (two-tailed).

Figure Caption

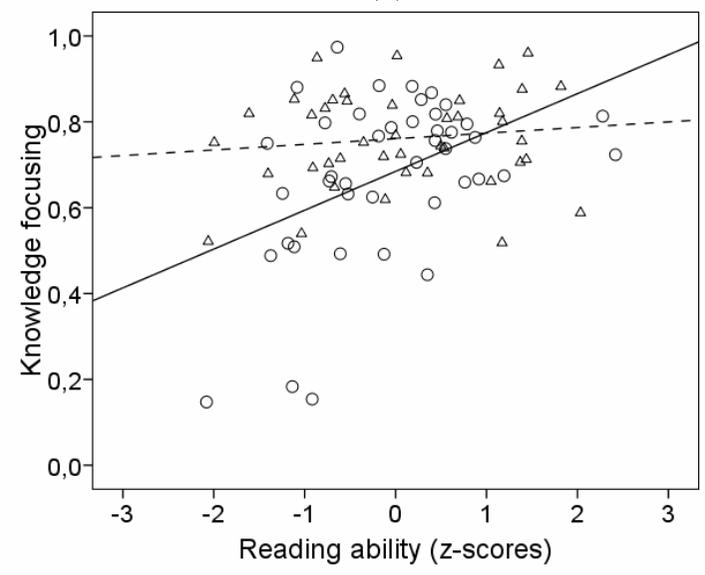
Figure 1. Main and interaction effects of reading skill and text structure on amount of knowledge, knowledge focusing, and degree of integration in Experiment 1 (a - c) and Experiment 2 (d - f).

Experiment 1

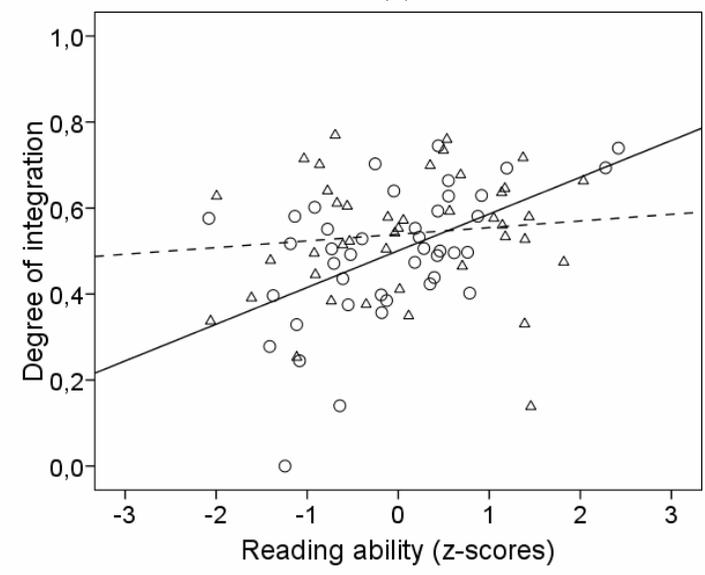
(a)



(b)

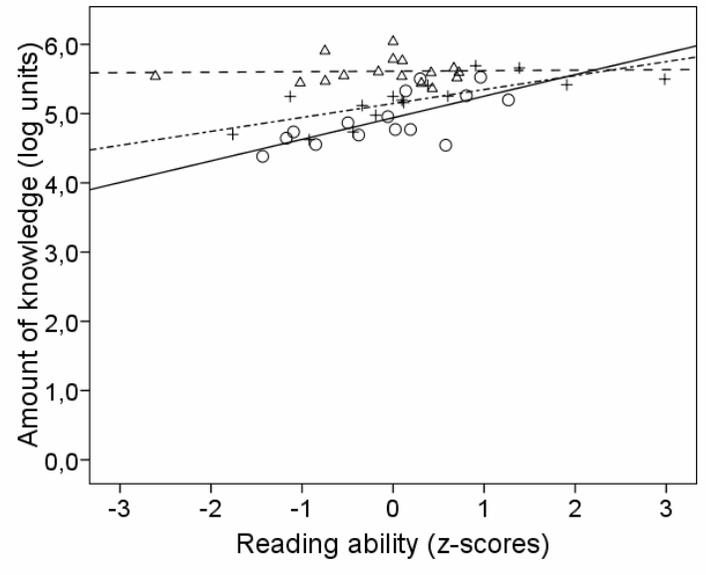


(c)

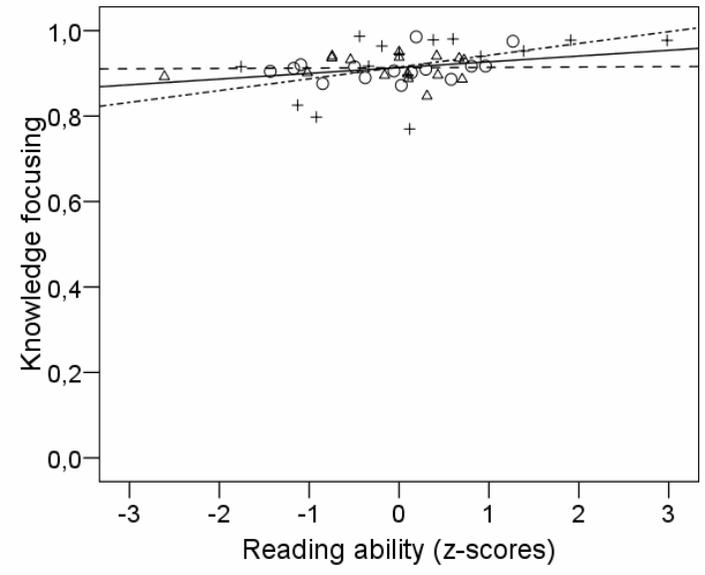


Experiment 2

(d)



(e)



(f)

