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Cognitive Overhead in Hypertext Learning Reexamined: Overcoming the Myths

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In hypertext learning, comparative research is mostly dedicated to differences in text-hypertext information retrieval and processing and to optimization of nonlinear information retrieval. Most of these investigations are conducted within the context of applied research. The theoretical background of information acquisition from linear and nonlinear text forms has not received much attention here. This article contributes to change the concept of cognitive overhead using text comprehension models as well as Cognitive Load Theory. Similarities and differences in cognitive load during text and hypertext comprehension are discussed in this context. The article suggests a contemporary model of cognitive load and text comprehension and presents evidence from a review of the literature and an initial empirical study supporting the proposed model.

The increased availability of electronically stored documents has led to a more frequent use of digital text resources in education. Especially in higher education, the ability of colleges or universities to create online-publications and e-learning opportunities provides a huge variety of materials across most disciplines.

Computer-based text formats differ in many characteristics from traditional print texts. The most common form beside camera-ready downloadable files (as many scientific papers or e-journals are presented) is the hypertext. Hypertext is also the basic format for World Wide Web (WWW or

Web) documents using Hypertext Markup Language (HTML). The nonlinear information retrieval allows readers or learners to access different paragraphs (nodes) in an almost self-determined manner merely depending on a hypertext author's navigation paths established within a hypertext. It is an ongoing debate among learning scientists whether the nonlinearity of hypertexts promotes learning or whether it is unbeneficial for knowledge acquisition (Rouet & Levonen, 1996).

Researchers and teachers pursuing a constructivist view of learning favor hypertext as a learning medium. Much of the research and its application have followed the Cognitive Flexibility Theory (CFT; Jacobson, Maouri, Mishra, & Kolar, 1996; Jacobson & Spiro, 1995; Niederhauser, Reynolds, Salmen, & Skolmoski, 2000; Spiro & Jehng, 1990). CFT states that learners benefit from an information retrieval that is a "landscape-criss-crossing" rather than a linear knowledge acquisition process. Hypertexts in context of CFT are viewed as adequate media to go beyond certain information, to (re-)visit certain facts at different times and in a different context. Thus, learners should ideally develop complex schemata that enable them to use their knowledge in a flexible manner.

Common to all these approaches is the use of hypertext in an attempt to present information in its full complexity and to enhance transfer by providing learners with the opportunities of thematic criss-crossing. Recent research has shown that this rationale does not necessarily meet the expected results. Some findings suggest disadvantages of jumping between themes (Niederhauser et al., 2000); others found only slight advantages (Jacobson et al., 1996) or only found an effect when instructional support was used in addition to hypertext learning (Stark, Graf, Renkl, Gruber, & Mandl, 1995). While these authors have used hypertext as a learning environment itself, other authors integrated hypertext learning resources into broader computer-based learning environments (Scherly, Roux, & Dillenbourg, 2000; Zumbach & Reimann, 2002) to enhance authenticity as well as transfer. The major rationale of these approaches is to integrate learning goals within scenarios and to use hypertext information access to support information seeking processes during problem solving. This gives hypertext learning a meaningful framework and should enhance learners' motivation by decreasing oversimplified learning scenarios and providing complex learning environments (note that the term "complexity" here addresses the complexity of the content or a domain and not the complexity of language that is addressed as another relevant issue in a following part of this article).

CFT and the integration of hypertext learning resources into a broader learning context represent two major approaches of hypertext learning applications and underlying research. Leaving the area of application in order to analyze basic processes of hypertext, reading comprehension is another major focus of past and current research. In this domain, the primary promising suggestions of hypertext or hypermedia[1] use in classroom or college have to be revisited. A decade ago researchers such as Berk and Devlin (1991) have stated that:

> Hypertext builds upon the relative strengths of the human mind and the digital computer: the computer holds the data and presents it to the human; the human chooses which way to go by pointing at each juncture. It is an intuitive approach in which the ability to link associated text matches the brain's natural tendency to think associatively. (p. 10)

In fact, information storage in the brain is only one instance involved in information processing. Since humans—as any other biological system—are incremental information processing systems (Langley, 1996), sequence does affect learning dramatically and thus, has to be considered in reading comprehension research. Particularly, when sequence is not standardized and instead individually determined such as in hypertext/hypermedia information retrieval.

PROCESSES OF INFORMATION RETRIEVAL AND INFORMATION PROCESSING IN TEXT AND HYPERTEXT LEARNING

Based on the model of reading comprehension suggested by Kintsch and van Dijk (1978; van Dijk & Kintsch, 1983) authors such as Gerdes (1997) remarked that especially for coherence building processes and schema acquisition the nonlinear media is associated with several problems. Above all, the necessity of designing locally coherent hypertext nodes makes it more difficult for learners to build interrelations between single nodes. It is, therefore more difficult for them to develop a global coherence or understanding of what a hypertext network conveys.

Major criticism regarding this point of view stems from theory of mental models (Johnson-Laird, 1990). According to the idea of mental models, the necessary information for establishing global coherence is generally established by reference to the related model. If the learner has no mental model or schema available with which the new information could be associated, the nonlinear media can be disadvantageous or fail[2].

Some research findings can be explained by text comprehension models, showing that hypertext learning does not lead to worse performance compared to linear text learning if students have a certain amount of prior knowledge in the learning domain (Gerdes, 1997; Lawless & Brown, 1997). Another problem with regard to these text-hypertext comparisons is the design of nodes itself: are they locally coherent and do they really require no additional information represented in another node to be understood? In addition, the link structure provided by the authors might be problematic: is the structure of hyperlinks exhaustive or are there confusing and unnecessary hyperlinks? Grabinger and Dunlap (1996) provide an overview on node and hyperlink design.

Another major problem in the analyses of differences between hypertext and text learning arises from the fact that existing theories of reading comprehension do not differentiate between linearity and nonlinearity. In particular, the model provided by Kintsch and van Dijk (1978) does not make a clear distinction between linear and nonlinear texts. Their model consists of several text-processing levels, yet only the two highest ones can be used to explain differences in text and hypertext comprehension. The stages are the *macro structure* on a propositional level with the building of inferences as well as the *super structure* related to the text type. Only these levels can be used to explain differences in text and hypertext comprehension due to the linearity and nonlinearity of text material.

Cognitive and metacognitive processes involved in reading comprehension and knowledge building, especially related to the selection of information and navigation planning, raise doubts about the existence of any relevant differences between hypertext and text reading. If we compare the learning progress of a person who is trying to build up an understanding in a certain, complex domain (e.g., with textbooks, scientific journals etc., as is common in higher education) with a person learning with and from a nonlinear information system, many parallels can be observed. Studying with a textbook for example requires making connections between paragraphs within the book, but also with other authors' opinions. In addition, to get deeper insight into a topic, learners have to integrate information of other experts from other books, journal articles, lectures, and so forth, to develop global coherent schema and expertise.

PROBLEMS DURING LEARNING WITH HYPERTEXT: FACTS OR MYTHS?

In hypertext learning research, the comparison between linear and nonlinear information resources and its effects on learners' cognitive outcomes is very common. Another research approach in hypermedia learning is to develop several tools and scaffolds in order to overcome problems in navigational issues related to the Lost-in-Hyperspace-Phenomenon or the Cognitive Overhead. One of the first authors that introduced these popular terms was Conklin (1987).

Lost in Hyperspace

The Lost-in-Hyperspace-Phenomenon, in particular, has provided a large scientific contribution. The goal is generally to overcome known obstacles with regard to navigation in nonlinear information resources including different structuring methods such as providing a hierarchical structure (Chen & Rada, 1996; Shapiro, 1998) or an alphabetical structure (Simpson & McKnight, 1990). Furthermore, tools for navigation and orientation such as visual organizers, maps, indexes, trailing or guided tours are part of this research (Gay & Mazur, 1991; Cunnigham, Duffy, & Knuth, 1993).

Lost-in-Hyperspace is a term for a variety of problems including situations such as a learner not knowing where he is at within a hypertext, not knowing how to get to a certain node or information, and not knowing whether the information is available within the hypertext, and so forth (for an overview see Foss, 1989 or Otter & Johnson, 2000). A lot of research including graphical overviews, site maps (, Chiu & Wang, 2000), specific types of links (Ruddle, Howes, Payne, & Jones, 2000), and so forth, has been conducted to avoid disorientation and to enhance navigation. Evaluation of supportive strategies such as the provision of navigational maps has shown that they are not always beneficial (Dias & Sousa, 1997). They only provide help to naïve learners (Möller & Müller-Kalthoff, 2000) or have to be adjusted to the presented content (Chiu & Wang, 2000).

However, we are mistaken if we assume that being lost-in-hyperspace is a unique problem of hypertext or hypermedia. Does a learner using a textbook already know beforehand whether the information they are seeking is in the book? Surely, there are opportunities to get an overview such as the table of content or an index, but these same tools can also be provided in nonlinear texts. In addition, headings and subheadings aid readers while reading a chapter or a book. The same support is usually provided to hypertext learners. Finally, readers can make annotations or marks inside a book. This is possible in hypermedia learning environments as well. Thus, the lost-in-hyperspace phenomenon does not seem to be a general problem of hypertexts but rather a common problem of badly designed hypertexts (and vice versa: a poorly structured book might also cause several problems in reading comprehension). Media literacy, in this case, is likely to be a mediating factor in helping to overcome such problems. Consequently, interaction effects between text design and linearity versus nonlinearity can occur[3].

Cognitive Overhead

Less interest has been dedicated to the second major problem described by Conklin (1987): the Cognitive Overhead. This phenomenon generally describes that readers of hypertexts have to focus on the question of which hyperlinks to follow. Cognitive resources of the working memory are occupied by this task, and are no longer available for information processing. Navigation planning and information retrieval in combination are comparable to the dual-task paradigm in cognitive science. In the context of this paradigm, it was demonstrated that while working on an additional task, the performance of the original intended task is worse. Inhoff and Fleming (1989) for example, provided evidence for the dual-task paradigm showing a negative impact of additional tasks on reading comprehension. Niederhauser et al. (2000) found evidence for decreased performance of hypertext learners studying in a nonlinear manner compared to learners using the same hypertext in a linear manner. Besides other aspects of their study, the navigation strategy of participants in relation to their learning outcome was investigated. The authors found that those participants who had employed an approximate linear information retrieval (which was possible in their hypertext) performed better in a knowledge posttest than those using a criss-crossing strategy that was not linear (which was also possible in the same hypertext learning environment). Niederhauser et al. (2000) explained their findings by Cognitive Load Theory (CLT; Sweller, 1988, 1994). CLT states that learning requires a change in the schematic structures of long-term memory. In particular, novices who try to develop and refine new schemata can have difficulties due to limited capacities in short-term memory (Britton, Stimson, Stennett, & Gülgöz, 1998). If a schema is available (e.g., by experts of a domain) new information will be integrated and working memory load (or cognitive load) will be low. Furthermore, the instructional material has an influence on working-memory load. CLT describes three different kinds of load: (a) Intrinsic Cognitive Load, which is the occupancy of resources according to the difficulty of a (basic) task, (b) Extraneous Cognitive Load, which is involved in higher order thinking processes, and (c) Germane Cognitive Load, which stimulates curiosity and problem solving.

Learning with hypertext leads to an increased Intrinsic Cognitive Load, if learning exceeds mere fact learning and demands the building of inferences. In addition, planning and evaluation of information retrieval occupies cognitive resources, an Extraneous Cognitive Load. This form of cognitive load can be reduced by choosing well-known reading strategies. Employing a linear information access strategy is an example of a method to reduce extraneous load, because linear reading is a well-known strategy that most adult readers have developed over many years of education and practice. Cognitive load does not always have a negative impact on learning processes. The Germane Cognitive Load enhances learning efforts like building inferences by fitting newly gained knowledge into existing schemata. All three types of cognitive load sum up what Conklin (1987) called Cognitive Overhead. This overhead occupies resources of the working memory that are not longer available for information processing.

If the basic assumption of a Cognitive Overhead was correct, learners working with linear texts should learn more effectively than learners with nonlinear texts. The explanation for this hypothesis is that learners with linear texts do not have to concentrate on navigation. However, does additional cognitive effort really lead to generally worse learning outcomes as postulated by Cognitive Overhead? If Extraneous Cognitive Load fosters learners to activate prior knowledge and to control their learning processes, a reduction of Extraneous Cognitive Load and an increase in Germane Cognitive Load might happen. Germane Cognitive Load ideally leads to an increased effort in elaborating information more deeply. To decrease Extraneous and to increase German Cognitive Loads is a major focus of many approaches in cognitive science and instructional psychology. Learning with hypertext requires a more thorough reflection of available information than learning with linear texts. Nonlinear information access and underlying processes of navigation planning make this reflection more likely to develop successful navigation strategies. This additional cognitive effort can lead to a deepened processing of hypertext-based information and thus enhance learning. Mayes, Kibby, and Anderson (1990), for example, suggested that disorientation derived from hypertext navigation could be a necessary and desirable part of the process of understanding. This is not always the case, as the study of Niederhauser et al. (2000) has shown. However, text linearity versus nonlinearity is not the only factor that has to be taken into account to explain learning outcomes. Many more variables involved in the learning situation have an impact on a learners' progress.

Comparing Text with Hypertext

In many studies, comparisons of hypertext and linear text use over-simplified learning material or learning sessions that only last for an hour or less. A generalization from such studies is problematic because they do not represent reading behavior in daily educational use where much more time is spent on journal articles or textbooks. Furthermore, the learning material itself cannot be used to make general conclusions. Many texts that are originally designed as nonlinear texts still have features of linear texts allowing learners to navigate in a linear manner. Consequently, differences in learning outcomes of studies using such "mixed" material can hardly be explained by linearity versus nonlinearity.

Studies using controlled comparisons related to linearity and nonlinearity of text and hypertext (Jacobson et al., 1996; Zumbach, Reimann, & Koch, 2001) did not show advantages of linear texts compared with hypertexts. In these studies, learners in the linear text conditions had more cognitive resources in order to process information (while not having to deal with navigation); however, their knowledge outcomes were not better than those of learners in hypertext conditions. A possible explanation for these findings might be that the learning material was not oversimplified and that in terms of Cognitive Load Theory Germane Cognitive Load was conditioned by a prior occurrence of Extraneous Cognitive Load in hypertext conditions.

Apart from aspects of complexity of learning material, the text type is a neglected variable in hypertext research. A common way of varying text material is to use instructional or scientific texts and present them in a linear as well as nonlinear format to college student samples. Here Kintsch and van Dijk's (1978) level of super structure might be suitable to explain interactions between text type and (non)linearity. Traditional linear texts such as fairy tales or other script-based texts appear to be less suited to be presented in a nonlinear format. Similarly, "traditional" nonlinear text formats such as encyclopedias are less likely to be processed in a linear manner due to the lack of coherence between single chapters.

However, the transition between linearity and nonlinearity is unclear. Especially in complex and ill-structured domains (e.g., in science) it is necessary to leave linear reading patterns and to read different paragraphs in different textbooks, journals, or other resources. In higher education, students' homework is often positively judged if many different sources are integrated, differences between authors' opinions are mentioned, explained, and argumentatively discussed. In order to meet these requirements, different sources have to be read (in many cases only selectively). The student leaving a linear level will achieve better results (or be faster than the student who only reads in a linear manner) and should develop more complex schemata. This is the point at which the Extraneous Cognitive Load meets Germane Cognitive Load and is beneficial for deeper learning.

Back to the concept of Cognitive Overhead: what Conklin mentioned as a problem of hypertext appears to be an overgeneralization, which does not meet the genuine complexity of written language. Research has not yet given a clear and unambiguous picture of the effects of linearity and nonlinearity. Therefore, additional, more specific models of text comprehension are required.

TOWARDS A CONTEMPORARY MODEL OF COGNITIVE LOAD AND READING COMPREHENSION

It has been argued that several postulated problems in learner-hypertext interaction lack both a theoretically and an empirically proven basis. It is interesting that in the past 20 years there has been a lot of research related to hypertext and its comparison with traditional text without getting a deeper understanding of the common or a unique underlying reading comprehension processes. In order to develop a theory of reading comprehension it is necessary to integrate the basic concepts of linearity and nonlinearity, the text design itself (i.e., the text structure) as well as the domain and the adequate text type (e.g., well-structured simple versus ill-structured complex texts).

The basic assumption in the following model is that differences in cognitive load in text or hypertext learning environments are caused by an orientation problem. This postulates that it is possible for a disorientation called "Lost-in-Hyperspace" to occur in linear as well as nonlinear texts. If there is no disorientation, there will be no need to plan for navigation and consequently no corresponding Extraneous Cognitive Load. Basically, disorientation is a consequence of unstructured texts caused by features such as missing paragraphs, headings, or text that contains complex sentence structures. This is the basic level of designing text-based instruction. Instructional decisions on this micro level have consequences on cognitive load that also affect instructional design decisions on a macro level. Disorientation is also likely to occur on a macro design level when (a) the narration format (e.g., like in a fairy tale) and (b) the presentation format (linear versus nonlinear) do not correspond. This should lead to an increased Extraneous Cognitive Load.

Furthermore, the complexity of the content and/or task should play a major role in evoking extraneous load. In this case, Extraneous Load is likely lead to schema activation and problem solving and, thus, fosters activation of Germane Cognitive Load. Therefore, in a condition with a highly demanding task (with a certain level of complexity) hypertext learners should benefit at least as much from their learning media as do traditional text learners (Mayes et al., 1990). Figure 1 summarizes the relationships drawn in the model.

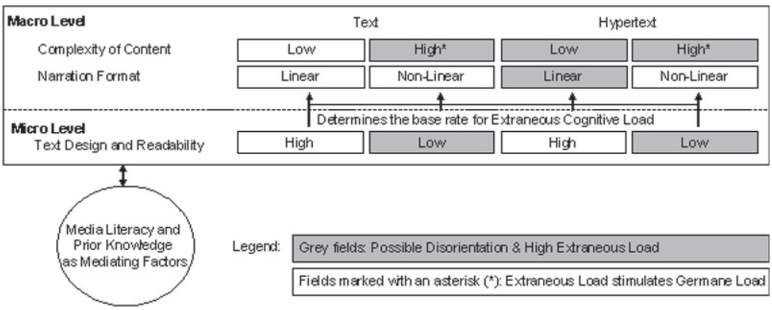

Figure 1. A model of cognitive load in text and hypertext comprehension

It is a crucial task for authors to provide a meaningful hypertext learning environment As Landow (1990, p. 40) stated:

The first fallacy, which has prompted now common skeptical grumblings about the hype in hypertext, takes the form that merely linking documents has major educational effects, that hypertext systems will solve most, if not all, educational problems, and that, therefore, once students have access to hypertext they will dramatically improve in some almost magical way.

Consequently, to allow the learner to develop higher-level skills, hypertext learning environments have to be of sufficient complexity. Oversimplification or short time treatments will not meet the potential of hypertext and will end up in "horse-race"-studies showing disadvantages of the nonlinear media.

EMPIRICAL SUPPORT FOR THE MODEL

Empirical proof for the suggested model comes from two sources. First, existing empirical results as mentioned earlier in this article point to the validity of cognitive load within hypertext learning with low or high complexity of contents. The meta-analysis of Chen and Rada (1996), for example, revealed that hypertext learning with highly complex tasks was more effective than hypertext learning with low complexity tasks. Findings suggest that high complexity might foster Germane Cognitive Load and, thus, motivation for problem solving.

Jacobson et al. (1996) conducted another study providing evidence for the model. In their study, different navigation possibilities in hypertext learning environments were experimentally manipulated. They compared the influence of guided thematic criss-crossing, learner selected thematic criss-crossing and free hypertext exploration on factual knowledge acquisition and problem-solving performance. These three conditions can be interpreted as three different levels on the continuum between linearity and nonlinearity. The performance of participants in knowledge tests in their experiment revealed only slight advantages of free hypertext exploration and learner selected thematic criss-crossing in one of four tested sessions (in the three other sessions no significant differences occurred). Furthermore, Jacobson et al. did not find significant consequences of the navigation variable on participants' performance in the problem-solving essays used as a measure of transfer. With the exceptions, no main effects of self-directed and predetermined navigation were found. This study suggests that providing the same content and just modifying the possibility of accessing this content (linear vs. nonlinear) does not have drastic effects if the task is complex.

A study conducted by Gerdes (1997) provided an example for a simple hypertext learning task. The author compared a linear text with a hypertext about geology. Both texts had about 3000 words. Subjects had about 1 ½ hours to learn the information provided by the texts. Outcomes revealed disadvantages in knowledge acquisition of the hypertext condition compared with the linear text condition. A second study also provided by Gerdes (1997) using a linear text and a hypertext dealing with philosophy also pointed in this direction (with a comparable amount of words as well as comparable learning time).

In addition, some of this research has also taken into account mediating factors such as media characteristics (Shapiro & Niederhauser, 2004; Walz, 2001) or prior knowledge (learners with prior knowledge benefit more from hypertext learning while naïve learners benefit more from linear text; Gerdes, 1997; Dillon & Gabbard, 1998; McDonald & Stevenson, 1998). Another mediating factor in hypermedia learning addresses learners' cognitive styles. Especially field dependency/independency appears to be a valid predictor of learner behavior within hypermedia learning environments

(Chen & Macredie, 2002; Ford & Chen, 2000). Chen and Macredie (2002) proposed a model of hypermedia learning based on learners' field dependency/independency. Field independent learners prefer an active and internally directed approach to learning material. Thus, they pursue independent learning and prefer free navigation that is provided by complex hypermedia learning systems. Field dependent learners prefer a passive, externally directed approach. Thus, they pursue guided learning and guided navigation that is provided by linear navigation. There is also evidence of influence of other learning styles on hypermedia learning outcomes and navigation preference such as Kolb's Learning Styles (Rourke & Lysynchuk, 2000) or *wholist-analyst* cognitive style (Graff, 1999).

Another mediating factor in hypermedia learning is media literacy. McDonald and Stevenson (1996) conducted a study presenting three different versions of a text: (a) an associatively linked hypertext, (b) a hierarchically linked hypertext, and (c) a linear text presented on a computer screen. They were able to show that, with a higher familiarity of presentation, learning outcomes and subjective familiarity with navigation also increased. The more linear the texts (associative structure < hierarchical structure < linear structure), the better were the results. This indicates that there is a continuum or dimensions of (non)linearity and that the familiarity with the medium directly influences navigation and outcomes. Familiarization with a linear reading strategy led to an ordinal effect favoring the more linear navigation possibilities. Van Nimwegen, Pouw, and van Oostendorp (1999) reported similar results. They were able to show that linear access by means of scrolling was more beneficial than a presentation of information following a paging principle. Furthermore, they found that "pure" hypertext organization structure (hierarchical only) was more beneficial for users than a mixed structure (linear and hierarchical). This disadvantage of mixed access might be due to a lack of an appropriate schema of information retrieval because learners in this study were neither able to pursue a genuine linear access nor a nonlinear browsing strategy. Furthermore, they used a city guide that had a content structure, which can be characterized as primarily not linear. Thus, organization structure within this learning material may have interacted with content although this was not explicitly examined by the authors. The hypothesis of interaction between content and its underlying implicit structure and hypertext organization structure is supported by a study reported by McDonald and Stevenson (1998). These authors faced learners with hierarchical, nonlinear and mixed organized hypertexts in the field of learning sciences (hierarchical structure with nonlinear, cross referential links). In this study, the mixed condition was superior. These results can again be explained by an interaction of content and organization structure. First, there was no mixed navigation involving linear and nonlinear information access. Thus, possible interference of corresponding navigation schemata was avoided. Second, hierarchical organization was realized between major concepts that were exclusively linked associatively only within these coherent concepts and not with others.

Despite these studies indicating that there is an interaction between content and organization structure, dimensions such as narration format, text design, and readability are rarely examined in hypertext research related to cognitive load investigations.

EMPIRICAL EVIDENCE FOR SUPPORTING THE MODEL: AN EXPERIMENT ANALYZING THE INFLUENCE OF TEXT COMPLEXITY IN TEXT AND HYPERTEXT LEARNING

A first study focussing on text design and dimensions of linearity/nonlinearity was conducted. The aim was to examine influence of text complexity on Cognitive Overhead and knowledge acquisition. The underlying assumption was that there is an interaction between complexity of text-based learning resources and presentation format: With complex learning material hypertext should be appropriate, whereas low complexity of content suggests the use of linear text material should be appropriate. The experiment itself was conducted to test the following hypothesis: There is an interaction effect between text complexity and presentation format (linear text vs. hypertext) on learning outcomes. Learning success is higher in hypertext learning when the material has a high complexity. With low complexity of content, cognitive load will inhibit learning with hypertext and, thus, provide higher learning outcomes with linear text.

Method and Design

A sample of 44 participants (all students at the University of Heidelberg with several majors) took part in this study. There were 14 male and 30 female with ages ranging from 20 to 41 years ($M = 26$; $SD = 4.6$). Participants were randomly assigned to one of the four treatment conditions. The study had a 2x2 factorial design with factor “linearity” (“hypertext” vs. “linear computer text”) and text complexity (“high” vs. “low”). The learning materials for this study were several modified texts about “e-learning.” The material had been modified correspondingly to the single treatment conditions.

Linearity varied between “nonlinear text” and “linear text.” The sequence in the linear text condition was fixed while in the nonlinear condition there were only associative Hyperlinks available without providing the possibility of linear access between nodes. In the nonlinear text, navigation was only possible by way of associative Hyperlinks.

Complexity of text varied between the conditions “high complexity” and “low complexity.” In the high complexity condition we used original scientific articles related to e-learning. The articles were adapted for screen presentation, specifically the conditions of presentation format. For the low complexity condition we modified the text material by using criteria derived from Langer, Schulz von Thun, and Tausch (1993). Therefore, passive sentence constructions were removed; outlines, thema-rhema combinations and summaries were added. Two independent raters judged the complexity of the text material on categories of simplicity, outline, and stimulation (Langer et al., 1993). Interrater reliability was $\kappa > 0.7$ (Fleiss & Cohen, 1973). The modified text (low complexity) was judged significantly more simple, better structured and more stimulating (one-sided Mann-Whitney U-Test with each $p<0.01$).

Procedure

Participants were instructed to elaborate the topic by working on a concept map. In a pretest prior knowledge (a 27-item test including multiple-choice and open questions covering the content of the learning material) and computer experience were assessed. Furthermore, an introduction in use of the software was given. During the treatment, participants had 40 minutes to navigate and read the texts and to work on the concept map. In a posttest the same knowledge assessment as in pretest, as well as an essay task, and a subjective assessment of the learning environment were applied.

Results

Results in learning outcomes and performance: Learning outcomes were assessed by means of the knowledge tests. Standardized questions (multiple-choice and open questions) were automatically evaluated and adjusted by probability of guessing (Lienert & Raatz, 1998, p. 69). Essays were evaluated by two independent raters ($\kappa = 0.85$). An overalls score was computed based on the knowledge test items (Cronbach’s Alpha = 0.77).

Another measure of knowledge acquisition was performance, measured by the quality of the concept mapping task. Participants' concept maps were compared to an expert solution giving one point for each correct linked single concept node (Ruiz-Primo, Shavelson, & Schultz, 1997).

As a basic measure of knowledge acquisition, the difference of knowledge test scores between pre and posttest was computed. Results contradict the global assumption of a Cognitive Overhead and confirm approximately the interaction hypotheses (Figure 2). Learning gain in the low complexity condition was higher than in the high complexity condition. In the linear text condition, the manipulation of text complexity had a higher impact on learning outcomes that in the hypertext conditions. As the variance was very high, neither the main effect of text complexity (ANOVA; F (1;40) = 0.35; p = 0´.56; ε = 0.09), nor an interaction effect of both independent variables occurred (ANOVA; F (1;40) = 0.18; p = 0.68; ε = 0.07).

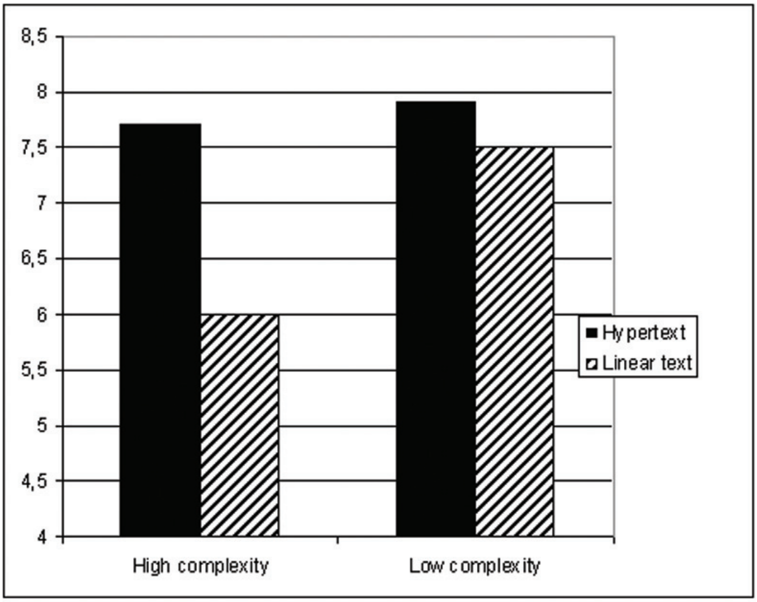

Figure 2. Gain in scores between knowledge pre- and posttest

Results from the essay analysis revealed a significantly better performance in hypertext conditions than in linear texts (ANOVA; F (1;40) = 4.3; p = 0.04; ε = 0.33). There was no main effect of text complexity (ANOVA; F (1;40) = 0.17; p = 0.68 ; ε = 007).

Analysis of performance in the concept mapping tasks was done by means of an Analysis of Covariance using participants' prior knowledge as covariate. Prior knowledge had a highly significant influence (ANCOVA; F (1;39) = 21.37; p < 0,01; ε = 0,74). Main effects just missed significance level, although in hypertext conditions participants were better in all complexity conditions than those in linear text conditions (ANCOVA; F (1;39) = 3,23; p = 0,08; ε = 0,29).

Taken together, in the knowledge test performance as well as in the concept mapping performance there was no evidence for a Cognitive Overhead. There was also no support for the postulated interaction hypothesis; no main effect of text complexity (ANCOVA; F (1;39) = 1.60; p = 0.21; ε = 0.2), nor was there a significant interaction effect of text complexity and text presentation format (ANCOVA; F (1;39) = 1.09; p = 0.30; ε = 0.17).

Results in subjective experience of the learning environment: Participants were asked to rate how the learning environment contributes to their learning on a five-point Likert Scale. Text with a low complexity was estimated as slightly more useful for the learning task as text with a high complexity (ANOVA; F (1;40) = 1.29; p > 0.05; ε = 0.18). There was a significant main effect showing that hypertext was estimated to be more helpful than linear text to conduct the learning task (F (1;40) = 4.83; p < 0.05; ε = 0.35).

Control variable: Experience with computers was assessed as a control variable. 90.9% identified themselves to be "average experienced" or "highly experienced" with computers on a five-point Likert Scale. Mean daily computer use was 2.15 hours (*SD* = 1.69); average daily internet use was 0.73 hours (*SD* = 0.66). There were slight, but no significant differences between the experimental groups.

DISCUSSION

We can conclude from the results that there is no evidence for a general negative effect of hypertext learning claimed by the assumption of Cognitive Overhead. The findings of this study, as well as contributing work from other authors, show that learning with nonlinear media might be as good as, or even better than learning with linear media if a learning task exceeds a certain threshold of complexity. In this study, hypertext learners were significantly better in essay task performance, and in a multiple-choice test, than learners with linear texts. A similar trend favouring hypertext was found in subjective estimates of usability of the presentation format.

A possible explanation for this unexpected main effect might derive from the operationalization of complexity in this study. Despite different ratings of complexity, all texts had a certain level of complexity that might have caused a ceiling effect. Furthermore, the complexity of the task and the content might also be a multidimensional construct resulting from several factors beyond the concept used in this study. A factor such as this is likely to be characteristic of the learning task and the learning goal, the complexity of a domain, available time, and so forth. In this study, all of these factors had rather demanding characteristics, which might have reduced the influence of text complexity varied only by means of linguistic understandability. Thus, the validity of this study is limited to complex learning tasks. The results suggest that learning with nonlinear information media led to equivalent or better outcomes than learning with linear text. This contradicts a global Cognitive Overhead assumption. Contrary to this assumption, outcomes revealed that by providing a complex task in an ill-structured domain (such as hypertext learning) possible disorientation may be an advantage rather than an obstacle. This is where a high degree of nonlinearity helps to meet the complexity of a domain.

GENERAL DISCUSSION AND SUMMARY

Learning with hypertext as nonlinear information media has initiated many educational debates about advantages and disadvantages of this text form. Many myths have accompanied this research from the Principle of Cognitive Plausibility to the concepts of Lost-in-Hyperspace and Cognitive Overhead. While the Principle of Cognitive Plausibility has lost its plausibility very quickly (Dillon, 1996), the Lost-in-Hyperspace-Phenomenon and the Cognitive Overhead still have an impact on contemporary hypertext research. This article intends to contribute towards overcoming these concepts by using established models of text comprehension and, thus, to develop a more precise model of learning with linear versus nonlinear texts. Therefore, a detailed analysis of interaction between different text types, complexity of content as well as text design parameters have to be taken into account. With the help of these different dimensions, detailed considerations of beneficial and unbeneficial relationships between linear and nonlinear text use and cognitive load are possible. It was argued that extraneous cognitive load is always combined with disorientation within a document; whether such a document is presented in traditional or digital, linear or nonlinear format. Disorientation or “Lost-in-Hyperspace” can have many origins that can be attributed to a lack of prior knowledge, a complex and ill-structured domain, or complex text design.

In terms of Cognitive Load Theory, which is more suitable and precise than the concept of Cognitive Overhead, this disorientation is associated with an Extraneous Cognitive Load. Under certain circumstances such as complex schema acquisition, this kind of load should not automatically lead to decreased learning performance due to limited working memory capacity. If a transition from Extraneous to Germane Cognitive Load takes place, a deeper and elaborated information acquisition process can be initiated.

Limitations of the suggested model mainly derive from the concepts of linearity and nonlinearity. It is difficult to assume a bipolar dimension here. Instead we find a continuum where the extreme poles cannot be reached. Linear texts always open the possibility of nonlinear information retrieval. Nonlinear designed texts always have a link structure determined by the author that has linear navigation features.

Hypermedia learning possibilities such as the Web provide a variety of material between linearity and nonlinearity. The structure of such learning environments is only one key feature influencing learning processes and outcomes. In addition, media use and instructional message design are core factors determining the success of hypermedia learning environments. Basic principles like the modality effect can be used for designing multimedia rich web-based online courses in order to support learners (Mayer & Moreno, 2003). By providing flexible and adaptive access to web-based learning material, learners with different needs and cognitive styles can be addressed likewise (Bajraktarevic, Hall, & Fullick, 2003). Thus, learners preferring an active, problem-oriented and self-directed way of learning may benefit from ill-structured hypermedia learning environments that lead to an increased cognitive load. But also learners preferring a passive way of information access may benefit from web-based courses that can be adapted to their needs (Koc, 2005).

It is obvious, that further experimental research has to address the interaction of text, (non)linearity, cognitive load and learner characteristics to allow precise predictions about success or failure of hypermedia learning environments.

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Notes

[1] With new technology, the difference between hypermedia and hypertext is obsolete. The terms are used as synonyms here.

[2] This also addresses linear text use when no prior knowledge is available for integrating new information into existing schemata.

[3] The Flesch or the Flesch-Kincaid indices are examples for measuring readability. This article has a Flesch value of 77.8 (0 indicates a poor readability; 100 is the maximum value).