ハイパーテキストを利用した学習の効果向上のための探索 — 認知負荷理論に関する文献調査からの示唆 —

Exploring the Way to Improve the Effectiveness of Hypertext-Based Instruction: Inferences from the Literature on Cognitive Load Theory

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ABSTRACT

今日までに多くの実践家たちがハイパーテキストを利用し，教育ソフトウエアを開発して来た。ハイパーテキストは多様な形で情報を提示することができるので，様々な目標に最適化された学習を提供できると信じられてきた。しかしながら，ハイパーテキストは実際には高密度な情報によって人々を圧倒し，学習を妨げるということが研究者達によって言及されて来た。また，ハイパーリンクを含んだ文章では持続的な読解が困難であるということも報告されている。本研究では認知負荷理論に関する文献調査を通して，ハイパーテキストを利用した学習を改善する方法について考察した。文献調査の結果，ハイパーテキストは構造設計と学習内容を適切に選択することで意義のある学習を実現させることができると分かった。また，ハイパーテキストを利用した学習がモチベーションを向上させる可能性も示唆された。本論文はハイパーテキストを使った教材に関する六つの原理と，将来の研究への示唆で締めくくられている。

To date, a large number of practitioners have created instructional software with the technology of hypertext. Because the technology can present information in multiple ways, it was believed that hypertext would provide instructions optimized for various learning objectives. However, researchers have mentioned that hypertext actually distracts learning by overwhelming people with the high density of information. It is also reported

that people cannot perform sustained reading with passages including hyperlinks. This study explores how to ameliorate hypertext-based instruction by reviewing the literature on cognitive load theory (CLT). The present study found that hypertext could bring about meaningful learning with appropriate selection of structural design and learning contents. It also found that hypertext-based instruction could increase motivation. In conclusion, this paper suggests six principles for hypertext-based instructions with recommendations for the methodologies of future studies.

Introduction

Hypertext was developed in 1945 and has evolved rapidly and continuously since then (Nielsen, 1990). Rouet and Potelle (2005) define hypertext as "a complex electronic document made of a network of pages connected through hyperlinks" and a hyperlink as "a verbal expression (usually a word) in hypertext page that can be selected to display another related page" (p. 309). Nielsen (1990) mentions that some people use the term 'hypermedia' instead of 'hypertext' to put more emphasis on multimedia aspects of hypertext. However, in order to avoid confusion or extraneous cognitive load, the present study uses 'hypertext,' the preferred term in Nielsen (1990).

Many practitioners to date have developed hypertext-based instruction because they thought it would improve learning. Brusilovsky (1997), for instance, believed that hypertext would provide different documents in different ways according to different characteristics of learners. However, it has also been suggested that hypertext could actually hinder instruction (Eveland, 2001). Amadieu, Tricot, and Mariné (2009) observe that people need to think of "their own reading sequence" when they are reading hypertext (p. 381). That might be the reason why people could get "lost in hyperspace" (Edwards & Hardman, 1989). Additionally, Liu (2008) contends that the nonlinearity of hypertext disables people from concentrating on one thing.

Problems with hypertext could be, in part, explained in terms of cognitive load. Cognitive load consists of three sub-elements: intrinsic, extraneous and germane cognitive load. In order to achieve successful learning, the three types of cognitive load integral cannot exceed the limitation of short-term memory. According to Paas et al (2003), intrinsic cognitive load is an indicator for complexity of learning contents while germane cognitive load is an indicator for meaningful learning. Extraneous cognitive load is an indicator for "unnecessary" elements and, therefore, "ineffective" instructional designs. It is considered by the majority of researchers (e.g., de Jong, 2010) that intrinsic cognitive load is unchangeable. Thus, instructional theories primarily focus on diminishing extraneous cognitive load and increasing germane cognitive load (e.g., Mayer, 2009).

This paper will explore following two questions. In what ways can negative aspects of hypertext be diminished? In what ways can hypertext work positively? The present study will investigate characteristics of hypertext to answer these questions by reviewing the literature on cognitive load theory (CLT), which largely contributes to the field of instructional science (Paas, Renkl, & Sweller, 2003).

Method

This study reviews articles from five leading journals of instructional technology and cognitive science: British Journal of Educational Technology; Computer in Human Behavior; Educational Psychologist; Educational Technology Research and Development; and Instructional Science. The five

journals are retrieved from the publication lists of three leading authorities in cognitive load theory: Fred Paas, John Sweller, and Richard E. Mayer. The 2009 impact factors for the five journals are ranging from 1.183 (Educational Technology Research and Development) to 3.60 (Educational Psychologist).

In order to perform systematic selection of articles, this study incorporates two literature review approaches introduced by Bruce (2001). The first approach is "subjective approach" namely, "breadth, relevance, authority and exclusion" (p. 163). The second approach is "objective approach," that is "topicality, comprehensiveness, availability and timeliness" (p. 163). While he puts more emphasis on the "subjective approach," the present study adopts both objective and subjective approaches to select up-to-date articles of cognitive load theory. In brief, following criteria are applied to the selection of literature:

Objective Criteria

- *Topicality*: articles placed in a special issue of cognitive load theory, or articles which contain the phrase 'cognitive load theory' either in title, keyword or abstract.
- *Timeliness*: articles which are published after the year of 2000.

Subjective Criteria

- *Relevance*: articles which seem to be related or applicable to hypertext.
- *Authority*: articles written by authorities on cognitive load theory were prioritized.

The numbers of articles which met the objective and subjective criteria are indicated in Table 1.

Articles that fulfilled the objective criteria are equal to articles read to conduct the present study. However, due to the limitation of space, the reference section does not introduce every paper that informed the author. It is hoped that readers will also take a look at these articles.

Besides 65 articles of five journals mentioned above, three books dealing with cognitive load theory are reviewed in order to compensate for the limited coverage of the literature to recent studies:

- *Cognitive load theory* (1st ed). Cambridge University Press.
- *Multimedia learning* (2nd ed). Cambridge University Press.
- *The Cambridge handbook of multimedia learning* (1st ed). Cambridge University Press.

Finally, in order to perform a comprehensive analysis, articles cited in the literature and articles on hypertext are given equal consideration when appropriate.

Key Aspects of Hypertext and Cognitive Load Theory

Careful analysis of the journal articles, three major books and other references helps the author identify seven key aspects of hypertext: placement of hyperlinks; method of providing information; placement of supplemental information; selection of learning content; selection of supplemental information; implementation in language learning; and the possibility of improving motivation.

Table 1 Number of Articles Fulfilled the Objective and Subjective Criteria in the Five Major Journals

Journal	Objective Criteria	Subjective Criteria
British Journal of Educational Technology	2	1
Computer in Human Behavior	37	9
Educational Psychologist	9	5
Educational Technology Research and Development	8	3
Instructional Science	9	1
Total	65	19

Placement of hyperlinks

Bernard, Hull, and Drake (2001) conducted a study to compare four different kinds of hyperlinks, "links embedded in document," "links at bottom," "links at top-left" and "links corresponding with document" in reading comprehension. The participants were asked to answer ten questions related to the reading passage and, among the questions, six questions required them to read pages behind hyperlinks. The performance were measured in terms of the number of correct answers, time spent on the task, and frequency of clicks as an indicator for "search efficiency." After the completion of the reading task, the participants answered a questionnaire asking their perceptions for the type of hyperlinks they were assigned. As a result, there were no significant differences in observable performances probably due to the small number of participants, five for each group. However, although the effect was marginal, hyperlinks embedded within a reading passage are perceived as easiest to navigate.

Edwards and Hardman (1989) performed a similar study twenty years ago with nine participants for each group. In their study, they concluded that embedded links, in their word "hierarchy condition," gained the reader's satisfaction most and increased efficiency toward the end of the reading session. An example of embedded hyperlinks or hierarchical hypertext is presented as Figure 1.

In addition, Amadieu et al (2009) also investigated the effects of embedding links within a passage: the participants are twenty-six or twenty-eight for each group. It was found that those who had less domain-specific knowledge performed better on recall when they read hypertext of hierarchical structure. While this kind of difference was not observed in the case of participants who had more domain-specific knowledge, hierarchical structure seems to be beneficial for everyone regardless of prior knowledge as it has a possibility of improving readers' perceptions.

Method of providing information

"Even though the effectiveness of embedded links has been demonstrated, they should be considered a complement rather than an alternative to content representation pages" (Rouet & Potelle, 2005, p. 302). What could be inferred from their notion is people could be overwhelmed by the increase of

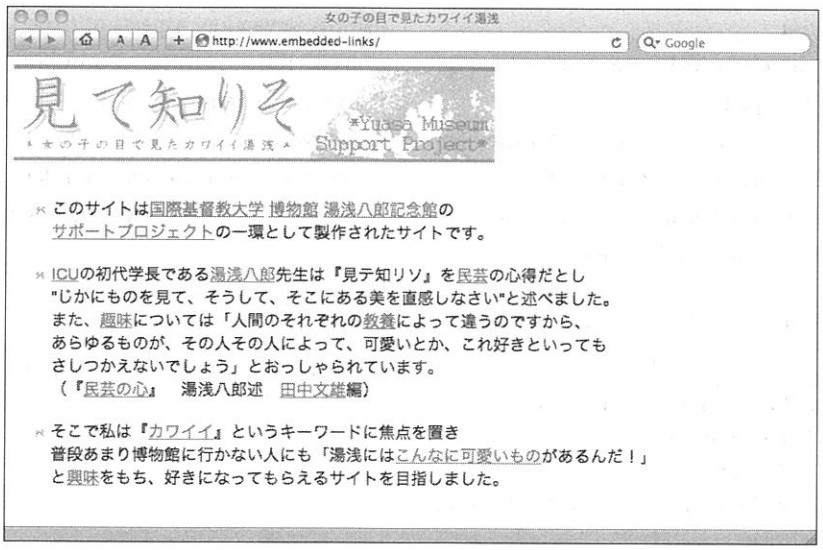

Figure 1. An example of the embedded links.

extraneous cognitive load if pages behind hyperlinks contain primary components of learning. Thus, information in pages connected by hyperlinks should be supplemental, rather than necessary information for everyone. There are grounds for giving certain information separately as additives, which seems to be the primary rationale for hypertext-based instruction.

According to the expertise reversal effect of cognitive load theory, instructions that are optimized for novice learners could interrupt learning of experts (Kalyuga, 2005; Kalyuga, Ayres, Chandler, & Sweller, 2003). This expertise reversal effect can happen when instructions provide information which is unnecessary for high-prior knowledge learners. Unnecessarily elements can increase extraneous cognitive load. Thus, it is important to provide instructions of an appropriate level at the appropriate time (Kalyuga, 2010; van Merriënboer, Kirschner, & Kester, 2003). These are the justifications for providing some materials separately in the behind of hyperlinks.

However, some may feel that it would be a more certain way to avoid expertise reversal effect to develop instructions for novices and experts separately. This is actually the most difficult part of cognitive load theory. "Designs that seem to elicit extraneous processes may, at the same time, stimulate germane processes" (de Jong, 2010, p.108). In some cases, instructions that could reduce extraneous cognitive load would also diminish germane cognitive load. Especially, because there is no perfect measurement of cognitive load, it is safe to provide possible-extraneous contents at the back of hyperlinks rather than eliminate them completely. Actually, letting learners change the features of multimedia could reduce cognitive load (Zheng, McAlack, Wilmes, Kohler-Evans & Williamson, 2009). Thus, giving supplemental information in the way learners could receive at their disposal is recommended.

Placement of supplemental information

Another factor of extraneous cognitive load that is originated to learners' characteristics is spatial ability. Low spatial ability could increase extraneous cognitive load (Plass, Kalyuga, & Leutner, 2010), which means instructional materials should be created in the way they do not surpass learners' spatial ability. Accordingly, showing relative learning elements in near place at the same time could improve learning: "spatial contiguity principle" and "temporal contiguity principle" (Mayer, 2009; see also Mayer & Moreno, 2010). However, there seem to be at least two problems in applying these principles.

First, learners might have already studied the 'relative information' and providing this information could cause extraneous cognitive load. As mentioned earlier, giving learners controls on the choice of learning contents is important for meaningful learning, which seems to be inharmonious with the two contiguity principles. Second, if learners have very little previous knowledge, it is, from the beginning, difficult to show all elements they need at the same time, in the same place. Liu (2008) observes that people often construct "a visual memory" while they are reading, and scrolling on digital reading could distract this process (p. 55). Probably, pages that contain a lot of elements should be long and require scrolling and, therefore, could interrupt reading.

In order to achieve solutions for these problems, as with the saying 'learning from the past,' some relatively older literature on hypertext was reviewed. As a result, it was found that Brusilovsky (1997) introduced "frame-based technique" as an effective method of creating interactive hypertext. Indeed, the most straightforward way to resolve the conflicts between the expertise reversal effect and the two contiguity principles is to use a frame-based webpage (see Figure 2).

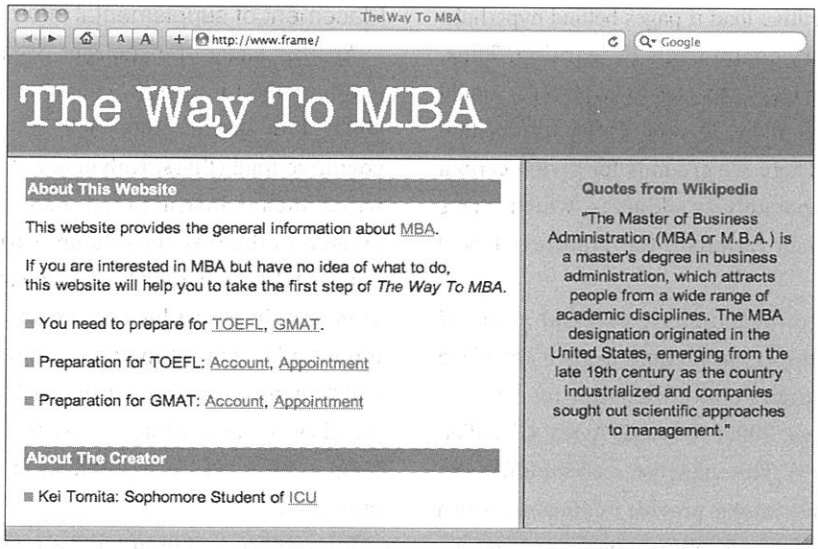

Figure 2. An example of the frame-based webpage.

As indicated in Figure 2, frame-based websites can have multiple pages within one window and, therefore, can show relevant materials near to each other. In addition, the frame-based website could provide an environment where learners can see relevant materials at their disposal when it is combined with hyperlinks. Thus, frame-based websites could create hypertext-based instructions which comply with both of the expertise reversal effect and the two contiguity principles.

However, World Wide Web Consortium (W3C) does not currently recommend the usage of frame-based websites. Thus, it is recommended to create a frame-like website (see Figure 3) with the usage of Cascading Style Sheet (CSS).

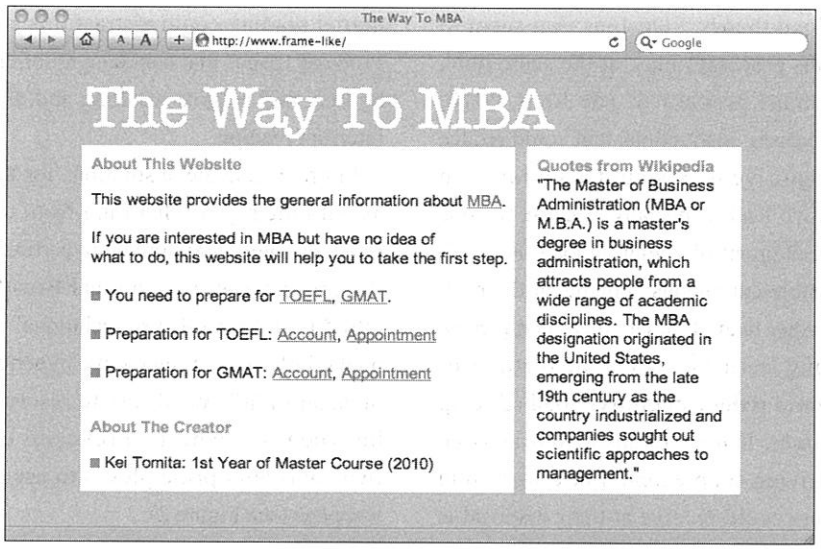

Figure 3. An example of the frame-like webpage.

Selection of learning content

There is an interesting suggestion from the study of Berthold, Röder, Knörzer, Kessler and Renkl (2010). They compared learning with and without "explanation prompts" ($n = 40$) and identified the "double-edged effects" of providing supplemental information. The effects are, providing supplemental information could enhance learning of "conceptual knowledge" but it also prevents acquisition of "procedural knowledge" (p.6). It could be inferred from these findings that providing supplemental information with hyperlinks is more suitable for the learning of facts or concepts, rather than learning of practical skills.

An example of factual learning is provided by Reinking (2005): "computers may expand opportunities to children reading independently when an adult or knowledgeable reader is unavailable to provide individual assistance with any word in text" (p. 367). Novice readers, by definition, should feel difficulty of reading. Consequently, reading passages that consist of a lot of unknown words would exceed the limitation of their short-term memory. Until they become familiar with reading, it seems appropriate to provide annotations for difficult words in their reading passages. Actually, it was found that annotating definition could be beneficial for reading (Wallen, Plass, & Brünken, 2005). Thus, it is recommended to use hyperlinks in order to supply explanations for words or phrases in learning of concepts or facts.

Selection of supplemental information

The fifth aspect of hypertext is related to the issue of appropriate selection of supplemental information. There are some suggestions from the theories of human cognition. According to Mayer (2009), creating connections between learning contents and learners' prior-knowledge is important for meaningful learning. In addition, Hollender, Hofmann, Deneke, and Schmitz (2010) point out that several elements in learning materials could be considered "a single element" if learners can conceive meaningful connections between these elements. If learners successfully activate their prior-knowledge, they will experience reduced extraneous cognitive load (Kalyuga, 2005; Kalyuga, 2010; Kalyuga et al., 2003). Therefore, an appropriate choice of supplemental information depends on learners' prior-knowledge. In other words, information that can be connected with learners' prior-knowledge will enhance learning more easily. For instance, providing synonyms familiar with learners would be helpful in learning new vocabulary, especially because synonyms are shorter than definitions and rarely contain 'extraneous' information.

Implementation in language learning

Liu and Lin (2010) conducted a study ($n = 80$) that compared three types of dictionaries, "pop-up dictionary," "type-in dictionary," "conventional book dictionary," and a control group. In their study, the "pop-up dictionary" which showed definitions of clicked words within the passage, namely embedded hypertext, was proven to be most efficient in learning vocabulary. While the group of "conventional book dictionary" spent the longest time on reading definitions, the group performed worse in recalling checked words than the "pop-up dictionary" group. They attributed this phenomenon to extraneous cognitive load. In addition, it might be noteworthy that the group difference did not affect on the reading comprehension scores. There seems to be two possible inferences from their study about hypertext-based learning:

- Reducing time of checking up words by annotating definitions using hyperlinks would help acquisition of new vocabulary.
- Reducing time of checking up words would not improve reading comprehension. Although the learned vocabulary "may be helpful in future

readings" (Liu & Lin, 2010 p. 9).

There is also a suggestion for reading aids in the case of second language. Plass and Jones (2005) advise to provide supplemental information in the first languages of learners, instead of the languages of the main text. They also imply situation might be different in the case of advanced learners. For instance, again, providing synonyms familiar with learners might bring about meaningful learning.

Regardless of the language proficiency, however, providing options to choose "visual versus verbal annotations" is helpful to acquire the target language (Plass, Chun, Mayer, & Leutner, 2003, p. 480). Indeed, there seem to be many cases in which visual annotation is more effective. Without Figure 1, for instance, some readers would not catch what 'embedded hyperlink' meant. However, forcing readers to see both visual and verbal annotations should be avoided because it causes extraneous cognitive load especially for advanced learners (Plass et al., 2003). Again, hypertext can let learners decide if they receive certain information and, therefore, could help the creation of meaningful instruction.

Possibility of improving motivation

Cognitive load theory has been ignoring possible impacts of motivation (Paas, Tuovinen, Van Merrienboer, & Aubteen Darabi, 2005). However, Pass et al (2005) also admire the existence of one motivational theory which has brought profound wisdoms to the field of instruction: ARCS model. This section will review the motivational strategies of ARCS model in order to examine if the six suggestions above could have motivational effects.

There are three strategies presented by Keller (1987) that seem to be compatible with the suggested principles of hypertext-based instructions. He suggests the "use of analogies familiar to the learner from past experience" (p. 4) to improve learning motivation. This suggestion could be explained as providing supplemental information relevant to learners' prior-knowledge: see *Selection of supplemental information*. Another suggestion to "provide personal choices for organizing one's work" (p. 4) seems to be compatible with the idea of providing supplemental information in the way learners could receive at their disposal: see *Method of providing information*. Finally, a suggestion to "provide informative, helpful feedback when it is immediately useful" (p. 5) could support the idea of presenting the supplemental information together with the main texts: see *Placement of supplemental information*.

Keller and Suzuki (1988) recommend to "use teaching strategies that match the motive profiles of the students" (p. 413). Paas et al (2005) argue that motivation can be measured accurately with "mental effort" made by learners (p. 28). Correspondingly, it could be assumed that those who are not motivated would not devote their "mental efforts" very much. Thus, for lower-motivated learners, decreasing extraneous cognitive load through the use of hyperlink (e.g., Liu & Lin, 2010) would be helpful. To sum up, the suggested principles might be able to increase and sustain learners' motivations in the hypertext-based environment.

Conclusion

The present study is an attempt to explore strengths and limitations of hypertext based on the review of selected literature. The study found seven aspects of hypertext that could be explained by principles of cognitive load theory. These findings suggest some useful strategies for hyperlinks design that could reduce unnecessary cognitive load of the learner. Those strategies are

- to embed hyperlinks within main texts to reduce extraneous cognitive load.
- to provide supplemental information learners could receive at their disposal to reduce extraneous cognitive load and increase germane

cognitive load.

- to present the supplemental information together with the main texts to reduce extraneous cognitive load: consider the 'frame-like' design.
- to use hypertext for learning concepts and facts rather than learning skills to reduce extraneous cognitive load.
- to provide supplemental information relevant to learners' prior-knowledge to increase germane cognitive load: synonyms might surpass definitions.
- to use hypertext for learning vocabulary to reduce extraneous cognitive load.

Especially, the second, third and fifth principles seem to be compatible with the ARCS model and, therefore, could enhance learning motivation.

In order to see if these six strategies actually reduce extraneous cognitive load, future studies are recommended to use the secondary task measurement (see Brünken, Plass, & Leutner, 2003). "Secondary task performance is a highly sensitive and reliable technique" (Paas, Tuovinen, Tabbers & Van Gerven, 2003, p. 66) and it is also appropriate for measuring extraneous cognitive load (DeLeeuw & Mayer, 2008). Additionally, since the hypertext strategies seem to have a positive impact on motivation, it is suggested to incorporate motivational measurements for the future studies. All in all, it is hoped that learners in the future will enjoy more opportunities for successful learning through more effective usages of hypertext.

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