Effects of Knowledge Representation Formats in Learning Materials on Digital Reading Effectiveness: A Postprint

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Abstract

[Purpose/Significance] From the perspective of knowledge organization, this study investigates the impact of two different organizational forms on the reading effectiveness of learning materials, providing reference for subsequent research and application of knowledge representation in reading materials. [Method/Process] The study employed a between-subjects design, with 26 participants completing two types of reading tests: reading search tasks and memory tasks. Differences were compared through reading time, number of correct answers on tests, and users' subjective preferences. [Results/Conclusion] Experimental results show that users' performance in reading search tasks exhibited no significant difference; however, in memory tasks, the reading effectiveness of the tree-structured organizational form was significantly superior to that of traditional linear text passages. Furthermore, in user subjective preference evaluations, tree-structured materials demonstrated more advantages, characterized by clear logic and ease of memorization.

Full Text

Abstract

[Purpose/Significance] From the perspective of knowledge organization, this study explores the influence of two different organizational forms on the reading effectiveness of learning materials, providing references for subsequent research and application of knowledge representation in reading materials. **[Method/Process]** Using a between-group experimental design, 26 participants completed two types of reading tests: a reading search task and a memory task. Differences were compared through reading time, number of correct answers, and participants' subjective preferences. **[Result/Conclusion]** Experimental results show that participants' performance in reading search

tasks showed no significant difference between the two formats. However, in memory tasks, the reading effectiveness of tree-structured organization was significantly better than that of traditional linear paragraphs. Additionally, in subjective preference evaluations, tree-structured materials received more positive comments, characterized by clear logic and ease of memorization.

Keywords: learning materials; knowledge representation; digital reading; reading effectiveness

1 Introduction

E-books offer large storage capacity, economic and environmental benefits, and convenience. In the digital reading era, researchers continuously overcome their shortcomings compared to paper books while leveraging digital carrier characteristics to optimize e-book reading experience and learning effectiveness. As human-computer interaction research advances, functions such as note-taking, bookmarking, and simulated page-turning have been introduced, making it possible to simulate the physical experience of reading paper books through tablets and dedicated e-readers. In recent years, digital reading has become more prevalent, and e-book reading has gradually become an important component of modern reading experience.

The rapid development of internet technology has also drawn attention to research areas such as electronic classrooms and e-textbooks. Digital reading methods like independent reading and mobile audiobooks have become important pathways for self-improvement and acquiring new knowledge. To meet people's lifelong learning and mobile learning needs based on electronic reading, various mobile products utilizing fragmented learning have emerged. However, learning materials with strong knowledge content, such as professional textbooks and research papers, present challenges due to their difficulty and heavy memory burden, resulting in low reading efficiency and difficulty in quickly grasping information. Although reading effectiveness is greatly influenced by subjective factors such as readers' reading ability and language proficiency, objective conditions like the presentation and knowledge organization forms of learning materials themselves also deserve attention.

Research on knowledge representation forms in the field of knowledge organization is relatively mature, but there are fewer empirical studies in the digital reading field on how knowledge representation forms affect reading effectiveness. This study compares conventional linear paragraphs and tree-shaped mind maps as two learning material organization methods through user experiments to explore the feasibility of improving reading effectiveness by changing knowledge representation forms. Its innovation lies in integrating and expanding research in both knowledge organization and digital reading domains.

2 Literature Review

2.1 Knowledge Representation Forms

Based on the degree to which interrelationships among knowledge units are revealed, knowledge representation is generally divided into three types: set or linear structures, tree structures, and network (graph) structures.

Linear knowledge representation involves simple definition and collection of knowledge units. In textual reading materials, linear organization is limited to linearly arranged paragraphs, generally requiring reading processing to begin from the start of the first paragraph. Most paragraph-based text is presented linearly, and information organized in linear structures is often difficult to process effectively, leading to easy forgetting.

Tree structures, also called hierarchical structures, emphasize hierarchical relationships or level-based aggregation among knowledge units. The most typical application in information organization is library classification systems. Through hierarchical decomposition, book classification systems can effectively organize books for easy retrieval and utilization. Ontology is a further development of hierarchical structures, defined as "an explicit formal specification of a conceptualization." Ontology hierarchically organizes concepts, entities, and relationships, providing possibilities for advanced functions such as intelligent reasoning and prediction. For example, R. Fikes proposed frame-based representation. This hierarchical knowledge representation forms the foundation for artificial intelligence reasoning algorithms such as the Semantic Web and object-oriented design.

Graph structures, or network structures, reflect more semantic relationships compared to the previous two forms, capable of representing equivalence relationships, hierarchical relationships, and various refined semantic relationships among knowledge units. Unlike tree structures, nodes in network structures are more closely and multi-directionally connected. Although their readability is weaker, they can more fully reflect semantic relationships. Knowledge graphs built from ontologies represent continuous development in the artificial intelligence field. Cognitive psychology suggests that human cognitive and memory units are organized as knowledge maps, which are crucial for cognitive processes.

2.2 E-book Design

2.2.1 Physical Form Research on visual effectiveness of text shows that font type, stroke width, text size, information density, character and line spacing, screen brightness, and contrast all affect reading experience. Lü Yinxuan's research from a layout design perspective indicates that readers experience fatigue when reading large amounts of text content. Regarding fonts, although no significant differences were found in visual search performance for English fonts, users subjectively preferred Arial font. For Chinese fonts, users showed faster visual search reaction times when facing Song typeface.

Common e-book content organization forms include page-turning by keypress, scrolling at a fixed rate, and marquee-style presentation where only one or a few words appear sequentially in a fixed screen area. Research shows that among these three traditional linear organization forms, dynamic scrolling and marquee styles cause more reader fatigue and are less efficient than page-turning style, particularly in horizontally scrolling text. Information density, arrangement, and layout significantly affect cognitive processing efficiency. Multi-column arrangement, placing elements into columns, enables faster search efficiency. D. D. Suthers' research on collaborative task completion demonstrated not only the promoting effect of external information recording but also that different information recording forms affect final task completion outcomes.

Structured text arrangement perspectives mainly focus on web interface design. User interface text processing has established fixed design rules, dividing text into hierarchical blocks according to content, enabling users to clearly identify text blocks with different meanings. S. Krug proposed that visual hierarchy of text helps users quickly browse information. When reading, readers subconsciously and automatically decompose material's visual hierarchy, and this visual decomposition process helps users pre-process pages, quickly classify and organize page content, and distinguish priorities.

2.2.2 Content Organization Research has summarized current e-book content organization forms: linear organization, hyperlinked organization, multimedia organization, and knowledge base organization. Hyperlinking represents a major breakthrough from paper books, providing navigation functions through indexes and in-text links to help users locate information, introducing e-book design to the semantic level of materials. Current e-books mainly implement hyperlinks through navigation directories with tree structures reaching at most second-level headings, without fundamentally changing content presentation forms and granularity.

Hyperlink-based organization changes content-level organization through links representing relationships between information pieces, forming a non-linear organization that gives users higher freedom and selectivity in choosing reading depth. Research conclusions on reading effectiveness of hyperlink-based content organization are inconsistent. S. S. Klois et al.'s study of 13-year-old children showed that when reading explanatory articles in hypertext organization, children could build richer spatial models of reading objects. Zhang Zhijun et al.'s research using time-limited reading tasks showed that when learning time was limited, hypertext learning effects were superior to linear text, and presentation of inter-concept connections helped rapidly integrate knowledge under time pressure. However, when learning time was ample, no significant difference existed, possibly because users could independently infer and form relationships between sections when time pressure was low.

Nevertheless, non-linear structure e-books have certain problems. Research shows that constantly clicking links to jump between pages causes cognitive

load, and in cases with many hierarchy levels, users may forget their current topic due to multiple jumps. Under information search tasks, research shows that for both low-structured and high-structured materials, using lower-level hierarchical structures (within 4 levels) took significantly less time than linear paragraphs. However, this non-linear structure also increases extraneous cognitive load as selecting and clicking information requires cognitive resources, reducing resources for processing content itself and causing distraction. Xie Jihong et al.'s research on meta-comprehension judgment showed that reading hypertext-structured materials reduces readers' meta-comprehension judgment level, decreasing the match between self-assessed reading effectiveness and actual test performance, thus hindering self-regulation of learning pace. To address these shortcomings, research has proposed improvement solutions, such as optimizing navigation directory display design to alleviate user disorientation. Studies found that for long text materials, e-reading performed worse than print media in reading time and information query accuracy, but fewer studies have compared reading effectiveness differences between long texts and tree structures in e-reading.

2.3 Reading Effect Measurement

2.3.1 Measurement Indicators and Tasks Current reading measurement research mainly focuses on reading ability measurement in education. Recent digital reading research proposes a comprehensive framework for measuring digital reading experience, including 18 indicators such as reading speed, comprehension accuracy, and fatigue level. Standards for evaluating reading effectiveness in content comprehension mainly focus on reading process fluency and understanding accuracy. In research on font type and size and text information density effects, visual search task reading time, accuracy, and subjective preference were primarily used to measure reading effectiveness, with time and accuracy as objective indicators and subjective preference as a subjective indicator.

Many studies focus on reading speed and fluency, often using reading search tasks divided into reading and testing phases. For example, Zhang Zhijun et al.'s research limited users to different reading times in the reading phase, then recorded time for users to relocate correct answers in the testing phase, exploring interaction effects between content organization form and time stress. Accuracy research commonly uses memory tasks to examine reading effectiveness. For example, Sun Yueliang et al.'s design used time-limited reading memory tasks where users read within time limits, then materials were collected and users completed test questions from memory within time limits to examine correct answer rates.

2.3.2 Reading Materials and Measurement Tools For measuring learning effectiveness of written materials, common methods include reading tests. The National Assessment of Educational Progress (NAEP) classifies reading materials into three categories: (1) reading for literary experience; (2) reading for

information; and (3) reading to perform a task. The second category, acquiring information and knowledge through reading, suits this study's purpose.

For testing the second category, NAEP mainly divides into four dimensions: summarizing ability, analytical ability, associative ability, and evaluative ability, similar to the three aspects in the Programme for International Student Assessment (PISA) reading literacy framework: information acquisition, integration and interpretation, and reflection and evaluation. This study uses these frameworks to guide test development for information-based materials.

Many paper textbooks have begun using mind maps, chapter summaries, and table summaries to integrate scattered chapter content, systematizing and visualizing chapter knowledge and presenting connections between knowledge points. However, due to inherent limitations like page constraints, paper textbooks' knowledge structure diagrams lack sufficient node detail depth, and mind maps lack immediate links with main text content. E-book hyperlinks exactly compensate for this deficiency. Therefore, this study proposes introducing tree-presented mind map forms into e-textbook solutions.

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3 Research Methods

3.1 Experimental Design

Experimental participants were students with certain reading abilities (mainly university students). The experiment used a between-group design: one group first completed a reading search task with linearly presented Material 1, then a memory task with tree-presented Material 2; the other group completed tasks in reverse order to balance sequence effects. All experiments were conducted on computer screens.

The experiment recruited 30 participants (26 participated in the formal experiment, 4 in the pilot experiment), all from Peking University with a 1:1 gender ratio, aged 18-28, with education levels from undergraduate to doctoral. Due to high homogeneity in participants' academic, age, and educational backgrounds, no significant effects of these factors on reading effectiveness were found. To exclude prior knowledge effects, all 26 formal experiment participants rated their knowledge of test material-related content at 3 (average) or below, and their knowledge of developmental psychology and infant psychology at 2 or below.

3.2 Variable Definition and Measurement

The independent variable was reading material organization form, divided into linear structure and tree hierarchical structure. Linear materials used Microsoft Word page view presentation; tree-structured materials used mind map presentation generated by Mubu software.

Dependent variables were readers' reading effectiveness, measured from several

aspects: 1. **Reading time**: Time participants reported completing material reading. Shorter reading time indicates faster reading speed. 2. **Reading test scores**: Reflecting reading effectiveness. Test questions were mainly objective, including simple information extraction questions, example illustration questions, and comprehensive judgment questions requiring integration of multiple text sections. Considering time effects on accuracy and individual differences (some participants might spend more time memorizing for better test performance), reading efficiency was used to measure correct answers per unit time: the ratio of accuracy to time spent. 3. **Subjective feelings**: Participants subjectively evaluated learning effectiveness, emotions, etc., for both organization forms to further explore user experiences.

3.3 Experimental Materials

3.3.1 Electronic Device Carrier Given research constraints, the experiment uniformly used laptops as reading devices, controlling for e-book hardware effects on reading effectiveness. Linear materials used Microsoft Word reading layout; tree-structured materials used mind maps generated by Mubu software.

3.3.2 Content Materials Since literary works have narrative, thematic, and linear plot development characteristics, while learning materials focus more on knowledge exposition with less need for in-depth reading, theme exploration, and suspense reasoning, the experiment selected knowledge-intensive psychology materials belonging to the NAEP category "reading for information."

The content material was excerpts from Chapter 8 "Infant Emotion and Affective Development" from *Infant Psychology*. Material 1 (Infant Emotion Emergence and Development, 2,152 words) was used for the reading search task; Material 2 (Infant Attachment Development, 2,017 words) was used for the memory task. Linear paragraph presentation is shown in Figure 1 [Figure 1: see original paper]; tree mind map presentation is shown in Figure 2 [Figure 2: see original paper] (not all hierarchical nodes are expanded in the figure, but the lowest-level nodes of the tree structure correspond to detailed linear paragraphs).

3.3.3 Test Questions Test question design partially referenced the PISA reading test framework (see Table 1). For Material 1 in the reading search task, the test consisted of 6 multiple-choice questions with 4 options each. Questions 1-3 were simple information extraction questions with directly locatable content; Questions 4-6 were more difficult comprehensive analysis questions requiring comparison and integration of multiple material details.

Material 2 for the memory task had 7 questions (see Table 2). Questions 1-5 were single-choice questions about clearly stated content, with Questions 1-4 examining major points and Question 5 examining details under a specific knowledge node. Questions 6-7 were short-answer questions: Question 6 required example illustration to examine depth of material understanding, scored

0-3 based on illustration adequacy; Question 7 examined breadth of material memory coverage by listing similarities and differences, scored 0-7 based on number of key points covered.

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4 Results

4.1 Reading Search Task

In the reading search task, users needed to locate relevant information in materials based on questions. Results showed no significant differences between linear and tree material groups in completion time or correct answers across three question types. Both materials' completion times were approximately 7 minutes with large standard deviations. The linear material group was slightly faster on average, but not significantly so (t = -0.237, sig = 0.815). See Table 3 .

In subjective evaluation of difficulty and completion satisfaction, linear materials were rated slightly more difficult but without significant difference (t = 0.573, sig = 0.572). Completion satisfaction ratings also showed no significant difference (t = -0.661, sig = 0.515), though tree material group satisfaction was slightly higher. For correct answers, simple information extraction questions (1-3) showed no significant difference between materials (t = 1.477, sig = 0.165). Comprehensive analysis questions (4-6) had equal means with no differences. Total correct answers were slightly higher for linear materials but not statistically significant (t = 0.49, sig = 0.629). For reading efficiency per unit time, although linear materials showed higher efficiency, the difference was not statistically significant (t = 0.289, sig = 0.775). See Table 4 .

During the experiment, one participant (User 26) using tree materials for the reading search task did not open unrelated topics, only expanding sub-trees of relevant topics, using their own knowledge structure for selective browsing and knowledge point location, demonstrating the hierarchical organization function of tree structures.

4.2 Memory Task

The memory task was divided into completion time and accuracy dimensions. Results are shown in Table 5 . In the reading phase, the linear material group was slightly faster than the tree material group, while in the testing phase, the linear group was over one minute slower than the tree group, but neither difference reached significance (t = -0.426, sig = 0.671; t = 1.531, sig = 0.139). For total time spent, the linear group was slightly faster but not significantly so (t = 0.496, sig = 0.624). Standard deviations for all time measures were large, indicating substantial individual differences.

For participants' self-rated difficulty and completion satisfaction, tree materials

were rated more difficult (t = -0.685, sig = 0.5) and less satisfying (t = 1.608, sig = 0.121), but differences were not significant.

Reading accuracy score descriptive statistics are shown in Table 6 . Tree materials showed higher accuracy overall. The difference in correct answers for 5 detail-selection questions reached significance (t = -2.528, sig = 0.022), with tree materials performing better. Example illustration questions also scored higher for tree materials but not significantly (t = -1.148, sig = 0.169). Listing differences questions scored higher for tree materials but not significantly (t = -1.816, sig = 0.82). For total scores across all questions, tree materials scored significantly higher (t = -2.655, sig = 0.014).

For reading efficiency per unit time, tree materials showed higher efficiency. Levene's test showed F = 0.663, sig = 0.423, $\alpha = 0.05$, meeting homogeneity of variance assumptions. Results indicated significant group differences (t = -3.426, sig = 0.003, $\alpha = 0.05$), demonstrating that after controlling for reading time affected by user habits, tree-structured mind map presentation indeed enabled clearer memory of key points.

During the memory task using linear paragraphs, a few participants (Users 8 and 10) used the built-in highlighting function. Observation of highlighting sequence revealed they indeed read linearly line-by-line, similar to computer processing of linear lists. However, results showed no significant improvement in accuracy for users who used highlighting.

4.3 Subjective Preferences

To comprehensively understand user experiences with both presentation forms, the experiment concluded with a survey of subjective preferences to summarize differences in user experiences between the two learning material organization forms.

For tree materials, users mentioned far more advantages than disadvantages. The most frequently mentioned advantages were clarity, intuitiveness, and logical organization. Additionally, convenience for memory, conciseness, and highlighted key points were mentioned. Disadvantages included complexity, lack of smoothness, and interoperability issues. Users also noted that while tree structures were logically clear, they lacked reading appeal.

In contrast, due to greater familiarity with traditional linear organization, users reported that conventional linear text reading was easier, simpler to operate, and had a more fluent and interesting discourse form. However, they also commonly indicated difficulty grasping key points, unclear organization, low reading efficiency, poor memorability, and longer reading times at the content level.

5 Conclusion and Outlook

5.1 Conclusion and Discussion

This study compared performance differences between linear and tree organization forms of learning materials in digital reading through user experiments, examining both information search tasks and memory tasks. The study found that in reading search tasks, no significant differences existed between the two organization forms in time spent or reading efficiency. Previous research found that for information search and location tasks, linear text performed better, with tree-structured hypertext performance between linear and non-linear text. However, considering Word's column reading display, test material length, and structuring degree in this experiment, this conclusion has limitations. Users did not process text linearly from the beginning as expected during reading search tasks.

In memory tasks, this study found that tree materials significantly outperformed linear materials in detail accuracy and reading efficiency, indicating that mind map formats produce better objective reading effectiveness for e-books. This finding aligns with previous research showing that for users with low prior knowledge, tree structures improve reading comprehension and help users read more effectively. However, some users new to tree-based reading still subjectively felt 不适应, finding conventional linear paragraphs more familiar and comfortable.

The results have implications for learning material design and application, particularly as online learning becomes more widespread. Learning materials based on electronic media such as web pages and e-books are widely used in online courses. For example, tree-shaped hyperlinked concept maps could be designed based on online courses and learners' knowledge backgrounds to guide reading and learning effectiveness.

5.2 Research Limitations and Outlook

Due to experimental prototype interaction limitations, some users tended to continuously click hierarchical topic labels, causing repeated page switching and cognitive load/disorientation typical of hypertext. Directly expanding/collapsing the entire tree on the original interface better maintained location information. These different usage patterns affected user experiences and subjective evaluations.

Physical form control was insufficient for both material presentations, with no strict control over fonts, spacing, and other factors. Test material selection and question reliability/validity had certain issues. Test material selection, particularly for reading search tasks, was less than ideal due to short, highly structured paragraphs, resulting in no significant reading effectiveness differences between presentation forms.

This study found better reading effectiveness for tree materials in memory tasks but did not clarify the underlying mechanism. Future research could apply eye-

tracking technology to record visual perception in real-time without interfering with reading processes. Eye movement patterns may illuminate reasons for reading differences between the two material types.

Previous research found that users with certain knowledge backgrounds could effectively read linear texts, while tree structures benefited users lacking background knowledge through more concise organization and higher reading efficiency, though with insufficient material appeal. Since this study controlled for non-psychology backgrounds, the influence of material background knowledge familiarity warrants further research. In application, results could inform further exploration of learning material organization form improvements, with refined user groups for targeted design of new e-book types.

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Liang Changhao: Conducted experiments, analyzed data, wrote initial draft.

Zhang Pengyi: Research design, paper revision.