Postprint: A Study on Changes in User Cognitive Structure Before and After Exploratory Search

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Abstract

[Purpose/Significance] This study aims to detect changes in users' cognitive structures before and after exploratory search, thereby revealing the patterns and underlying reasons for such changes. [Method/Process] An experimental method was employed to obtain pre- and post-search concept maps from 30 users. The concept maps from both phases were evaluated and compared based on a concept map evaluation index system to identify patterns of change in users' cognitive structures. Furthermore, the characteristics of cognitive interaction between users and literature were analyzed to investigate their impact on cognitive structure enhancement. [Results/Conclusions] The findings indicate that changes in users' cognitive structures before and after search exhibit three distinct patterns: 66.6% of users demonstrated significant improvement in cognitive structure, 16.7% showed no change, and 16.7% achieved substantial refinement. The study reveals that cognitive interaction between users and literature text constitutes a crucial factor in improving cognitive structure.

Full Text

Research on Users' Cognitive Structure Changes Before and After Exploratory Search

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Abstract: [Purpose/Significance] This study aims to detect changes in users' cognitive structure before and after exploratory search to reveal patterns and reasons for these changes. [Method/Process] Using an experimental approach, concept maps from 30 users before and after searching were obtained and evaluated according to a concept map evaluation index system to identify patterns of cognitive structure change. The study further analyzed cognitive interaction characteristics between users and documents to explore their impact on cognitive structure improvement. [Result/Conclusion] The findings show that users' cognitive structure changes present three patterns: 66.6% of users showed significant improvement, 16.7% maintained unchanged cognitive structures, and 16.7% achieved substantial improvement. The study reveals that cognitive interaction with document full text is a crucial factor in improving cognitive structure.

Keywords: Exploratory search; Cognitive structure; Concept map; Cognitive interaction

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Since the 21st century, humanity has entered the knowledge economy era, where knowledge has become the most important resource and its dissemination and application serve as a major driving force for social development. In this context, users' information needs have changed dramatically. The simple question-answer model in traditional search engines can no longer meet individual innovation and development requirements. When facing complex work and learning problems, users need to interact with systems multiple times, continuously adjust search strategies to obtain multifaceted information, and process and utilize this information to accomplish learning, research, planning, or investigation goals. This exploratory, interactive, and iterative search model was named "exploratory search" by Marchionini [1]. Since 2006, exploratory search research has attracted considerable scholarly attention and gradually become a hot topic in information seeking behavior studies [2].

Research on exploratory search has primarily focused on search behavior characteristics, influencing factors, and system support. Regarding search behavior characteristics, Zhang Yunqiu et al. [3] found that users' search behaviors exhibit nodal changes, showing characteristics of shifting from quick browsing to detailed browsing and then to focused searching as cognition changes phase by phase. Yuan Hong et al. [4], using health search as an example, compared behavioral differences between query-based search and exploratory search, finding significant differences in keyword transformation numbers, visited webpage counts, and the number of webpages used. Regarding influencing factors, research has identified user cognition, domain knowledge, user emotion, search ability, and search tasks as primary factors. Zhang Min et al. [5] found through empirical analysis that user cognition significantly impacts exploratory search result satisfaction, with goal cognition and knowledge cognition positively affecting search result satisfaction. J. Mao et al. [6] confirmed through user experiments that higher domain knowledge levels improve success rates in completing exploratory search tasks. Xia Lixin et al. [7] discovered that emotional coping skills and emotional load have significant positive and negative effects on exploratory search duration, respectively. Wang Yu et al. [8] found that search ability significantly impacts most search behaviors and gaze frequency but has little effect on gaze duration. Yuan Hong et al. [9] analyzed search tasks and search abilities in exploratory search behavior, finding that more complex search tasks lead to deeper user exploration, and higher search abilities result in more active search processes. Regarding exploratory search system support, S. Lu et al. [10] developed a visual exploratory search system allowing seamless switching between browsing and retrieval to naturally complete exploratory search tasks. Y. Fukazawa et al. [11] designed an exploratory search system, proposing a ConceptNet-weighted query expansion algorithm and ranking algorithm for query expansion results, with experiments showing improved novelty and serendipity. H. Kai et al. [12] designed a Picass system providing possibilities for visualizing, analyzing, and exploring search results.

Exploratory search is a search activity centered on "users acquiring new knowledge," inevitably linking the search process with the learning process. Consequently, researchers have recently focused on the theme of "search as learning," exploring associations between various search behaviors and knowledge change characteristics. Since changes in users' cognitive structure represent an important indicator for evaluating exploratory search success, detecting users' cognitive structure has become a crucial research topic. To effectively and conveniently evaluate users' cognitive structure, scholars have conducted preliminary explorations and achieved some results. Some researchers have used self-assessment methods, evaluating perceived learning effects through questionnaires. For example, C. T. Kevyn, X. Zhang, and Han Zhengbiao et al. [13-15] had users self-evaluate learning from thematic perspectives, information synthesis, and information exploration effects. However, this subjective assessment has obvious limitations, as different users have different measurement standards, making results incomparable. Other scholars have had users complete specific test questions to assess cognitive structure, such as L. Nelson and U. Gadiraju et al. [16-17], who had participants answer domain questions and complete knowledge tests after searching, using scores to evaluate learning effects. Still, other scholars have had users draw concept maps to externalize their cognitive structures, proposing various indicators to measure cognitive structure levels. For instance, Y. Egusa et al. [18] and S. Hitomi et al. [19] measured users' post-search cognitive structures by counting node numbers and phrase frequencies in concept maps, finding significant changes in node and relationship numbers after searching. Song Xiaoxuan and Liu Chang [20] comprehensively evaluated users' pre- and post-search knowledge levels by combining knowledge quantity and quality, finding significant improvements in knowledge point numbers, knowledge breadth, and knowledge depth.

Overall, empirical research on users' cognitive structure changes remains limited, with insufficient attention to cognitive interactions between users and documents during exploratory search. This study argues that searching for and retrieving relevant documents constitutes only the first half of exploratory search; absorbing and utilizing document knowledge is the key factor in changing users' cognition. Based on this, this research conducts an in-depth study on users' cognitive structure changes before and after exploratory search, aiming to discover patterns and characteristics of cognitive changes during the retrieval process and explore how user-document cognitive interactions affect cognitive structure changes, thereby laying a foundation and providing scientific basis for user model construction.

2 Theoretical Foundation

The cognitive view of information science considers information search as a process of user cognition rather than document-query matching. It focuses on users' absorption and utilization of information, emphasizing changes in knowledge structure and cognitive abilities during information use [21]. Representative figures of the cognitive view in information science include Brookes, Belkin, and Dervin, whose theoretical systems are relatively independent yet highly complementary [22].

2.1 Brookes' "Fundamental Equation of Information Science"

Brookes (B. C. Brookes), inspired by Popper's "Three Worlds" theory, advocated that the task of information science is to explore and organize objective knowledge to improve knowledge utilization efficiency. To clarify the relationship between information and knowledge and the pattern of knowledge growth, Brookes proposed the fundamental equation describing information's role and knowledge structure: $\mathrm{K[S]} + \Delta\mathrm{I} \rightarrow \mathrm{K[S} + \Delta\mathrm{S]}$, where K[S] represents the original knowledge structure, ΔI represents the amount of information, ΔS represents the improvement effect, and $\mathrm{K[S} + \Delta\mathrm{S]}$ represents the new knowledge structure. Therefore, "information is that part of knowledge which changes a person's original knowledge structure" [23]. Brookes emphasized that information received by individuals must be subjectively interpreted through their own knowledge structure to become intelligence, and that once absorbed, it causes not simple addition of knowledge but certain adjustments or even reorganization of the knowledge structure.

The exploratory search process is not only about individuals finding relevant information but more importantly about processing and utilizing the found information—that is, the individual learning process. Learning effects are reflected in changes to users' knowledge structures. During searching, users coordinate searched information ΔI based on their own knowledge structure K[S] to produce a new knowledge structure $\mathrm{K[S} + \Delta\mathrm{S]}$. Measuring knowledge improvement ΔS is a key element in evaluating users' information absorption and utilization in exploratory search, requiring investigation of how users' knowledge structures actually change before and after exploratory search. This constitutes the main focus of this study.

2.2 Belkin's Theory

Belkin (N. Belkin) first distinguished between text and information, defining text as "a set of symbols organized purposefully by a sender to change the receiver's image," and information as "any text structure that can change the receiver's image structure" [24]. He further clarified that the fundamental problem of information science is "facilitating effective communication of needed information between producers and users." Belkin proposed the famous "Anomalous State of Knowledge" (ASK) theory, arguing that users have information needs because they recognize their own anomalous state of knowledge and turn to communication systems to retrieve texts from collections that might resolve this anomaly. Users discover the essential conceptual structure of these texts and interact with their own anomalous knowledge state [25]. In this interaction process, there are linguistic and cognitive levels. When information conveyed by documents cannot interact with the receiver's knowledge state, it remains at the linguistic level; when it interacts and produces new conceptual structures, it reaches the cognitive level.

Unlike fact-finding search, user-system cognitive interaction plays a crucial role in exploratory search. During exploratory search, there exists interaction and mutual influence between users' knowledge structures and documents' knowledge structures [21]. An author's text, including title, abstract, keywords, and full text, represents the knowledge structure the author hopes to convey. When users face system-retrieved documents, interaction brings them into a selective state, stimulating them to make certain selections from the document's knowledge structure, choosing information of specific value to incorporate into their own knowledge system, thereby improving their cognitive structure.

2.3 Dervin's "Sense-Making Theory"

Under the influence of constructivist learning theory, Dervin (B. Dervin) reexamined issues such as the nature of information, human agency, and the information transmission process, focusing on how people influence information meaning generation. Dervin argued that information sense-making results from the joint action of internal behavior (cognition) and external behavior (information), and that information seeking is essentially a subjective knowledge construction behavior [26]. Sense-making theory emphasizes that subjects actively construct meaning in the situations they face. Information transmission is actually the process where textual conceptual structures interact with subjects' knowledge and experience to produce new knowledge structures. Through multiple interactions with texts, people continuously construct and modify original knowledge structures through assimilation and accommodation, forming deeper, richer, and more flexible cognitive structures. Since subjects are no longer seen as passive recipients of intelligence but as actors who derive their own meaning from it, the information meaning understood by receivers is not entirely equivalent to the producer's original intent. Different users have different understandings of the same information, and the resulting meaning construction and cognitive structures also differ.

In exploratory search contexts, there are no standard answers. As active meaning-makers, different users have different original knowledge structures

K[S] and different knowledge improvements ΔS. Users rely on their own knowledge structures to absorb and utilize retrieved information, thereby generating new cognition. This new cognition is reflected not only in reorganizing original text concepts but also in creating new concepts. These new concepts different from the original text constitute the crystallization of users' rational cognition and externalize their creative thinking. Therefore, this study also explores innovative vocabulary characteristics in users' post-search cognitive structures and their relationship with ΔS.

3 Research Design

3.1 Research Questions

Users' cognitive structure changes before and after exploratory search are influenced by many factors. For example, tasks of different difficulty cause different cognitive loads [15], different retrieval platforms provide different feedback information [27], and different prior knowledge leads to different comprehension abilities in exploration [6], all affecting users' cognitive level changes. However, according to Belkin's theory, user-document cognitive interaction is also an important factor affecting cognitive structure changes, though corresponding empirical research is currently lacking. Based on this, this study focuses on how, under conditions of identical task difficulty, identical retrieval platform, identical prior knowledge, and identical learning time, users' cognitive structure changes will present what patterns, and what impact user-document cognitive interaction has on cognitive structure changes. Specifically, this paper addresses three questions: 1. How do users' cognitive structures change before and after exploratory search, and what patterns emerge? 2. What characteristics does user-document cognitive interaction exhibit? 3. Do user-document cognitive interaction characteristics affect users' cognitive structure improvement?

3.2 User Experiment

This study primarily employs experimental methods. To control for irrelevant variables, this experiment selected same-grade, same-major university students for a real-context experiment, collecting users' concept map data before and after exploratory search and literature reading data during the search process. Concept maps are graphical tools for organizing and expressing knowledge that can visually and intuitively present learners' cognitive structures [28]. Quantitative evaluation of pre- and post-search concept maps can identify patterns of user cognitive structure changes. Additionally, combining concept maps with user-read documents can reveal characteristics of user-document cognitive interaction. Finally, Pearson correlation analysis reveals relationships between the two.

3.2.1 Experimental Subjects Through literature review, we found that the average number of participants in exploratory search experiments both domestically and internationally is around 35 [2]. Therefore, this study's experimental subjects were 30 second-year undergraduate students majoring in Information Management and Information Systems at Wuhan University's School of Information Management, including 10 males and 20 females aged 18-20.

3.2.2 Experimental Task The premise of exploratory search is that users are interested in a field but lack specific understanding, with uncertain search task goals and no unified answers. Based on these characteristics, this study designed experimental tasks following exploratory learning principles, selecting network-related issues of concern to university students as task themes. The final experimental task was: "Social media is an important platform for the public to obtain information and express opinions; however, due to its open nature, it has also become a breeding ground for rumors. How should this be governed? Please search the CNKI database on the theme of 'Rumor Governance in Social Media,' select 10 high-quality documents for in-depth exploration learning, and present your learning results in concept map form."

3.2.3 Experimental Procedure To ensure smooth experimentation and consistent external factors such as network conditions and experimental environment, this experiment was conducted in a computer lab. Before the experiment began, researchers explained the experimental content, procedures, and precautions. Before searching, users drew concept maps based on their initial understanding of the theme without referring to any external materials. Users could choose familiar concept mapping software such as Xmind, Processon, or Mindmaster. After completion, they used the CNKI platform to search for relevant literature, selecting 10 high-quality documents for in-depth study. High-quality literature screening and study time were limited to 90 minutes (two class periods). Finally, in the third class period (45 minutes), users drew concept maps again based on their new understanding of the exploration theme. After drawing, users submitted the 10 high-quality documents they had read in-depth and their pre- and post-search concept maps, concluding the experiment.

3.3 Data Collection and Analysis

This experiment collected two types of data: (1) pre- and post-search concept map data from 30 users, totaling 60 concept maps; and (2) full-text data of 10 high-quality documents read by each user, totaling 300 documents. Concept maps represent users' cognitive structures, while document reading data forms the basis for analyzing user-document cognitive interaction. This section explains the analysis and evaluation of these two data types.

3.3.1 Quantitative Evaluation of User Cognitive Structure To detect user cognitive structure changes, we first need to quantitatively evaluate user-drawn concept maps. This research team previously proposed a quantitative evaluation system for cognitive structure in exploratory search based on sense-making theory and hierarchical semantic network models [29], including six quantitative indicators: richness, professionalism, and effectiveness of concept nodes, as well as connectivity, hierarchy, and exploratory nature of concept relationships, with different weights assigned according to relevant theory, as shown in Table 1 :

Table 1 Concept Map Quantitative Evaluation System

Indicator	Weight	Description	Scoring Formula
Richness (Syntax)	10	Ratio of total concept nodes to maximum nodes	S_1 = [Node Count ÷ max(Node Count)] × 10
Professionalism (Semantics)	15	Whether concept nodes are professional terms	15 if $n_1 = n_2$; 10 if $n_2 \leq n_1 < n_2$; 5 if $n_2 \leq n_1 < n_2$; 3 if $n_2 \leq n_1 < n_2$; 1 if $n_1 < n_2$ (where n_1 is professional term count, n_2 is total node count)
Effectiveness (Pragmatics)	20	Ratio of theme-relevant nodes to maximum theme-relevant nodes	S_3 = [Theme-relevant Nodes ÷ max(Theme-relevant Nodes)] × 20
Connectivity (Syntax)	10	Ratio of node connection lines to maximum connection lines	S_4 = [Node Relationship Count ÷ max(Node Relationship Count)] × 10
Hierarchy (Semantics)	15	Whether upper concepts precisely summarize lower concepts	S_5: 3 points per valid hierarchy, maximum 15 points

Indicator	Weight	Description	Scoring Formula
Exploratory Nature (Pragmatics)	30	Whether overall structure reflects novel and deep thinking	S_6: 30 points for rich connections and novel thinking; 24 points for relatively complete cognitive structure with deep thinking; 18 points for rich content but insufficient connection depth; 12 points for incomplete cognitive structure lacking theme-relevant nodes and connections; 6 points for few concept nodes with isolated and one-sided relationships

This study uses this index system to evaluate user cognitive structure. The total concept map score is the sum of six indicators: $S = S_1 + S_2 + S_3 + S_4 + S_5 + S_6$. S_1 measures concept richness (syntax level), examining only the formal number of concept nodes. S_2 measures concept professionalism (semantic level), examining whether concept maps contain professionally meaningful vocabulary. S_3 measures concept effectiveness (pragmatic level), as different nodes convey different values and importance levels. In the exploratory search context of "online rumor governance," node utility is reflected in whether it accurately describes theme-relevant content. Valid nodes are retained; invalid nodes are removed during quantitative evaluation. S_4 measures relationship connectivity (syntax level), examining only the formal number of connections. S_5 measures relationship hierarchy (semantic level), as hierarchical structure reflects individuals' deep understanding of organic connections between theme concepts and represents an important manifestation of cognitive ability. More hierarchical structures indicate stronger cognitive ability and higher scores. S_6 measures relationship exploratory nature (pragmatic level), assessing the value and utility of concept map connections, such as identifying hidden relationships between concepts. Therefore, five different grade scores are assigned according to the value of individual exploration results, as shown in the table.

Using this quantitative evaluation system, we scored pre- and post-search concept maps for 30 users, calculating score differences as assessments of cognitive structure changes.

3.3.2 Coding of User-Document Cognitive Interaction Each user finding 10 high-quality documents constitutes only the first half of exploratory search; absorbing and utilizing document knowledge is the key factor in changing user cognition. During document reading, users continuously interact cognitively with documents, absorbing intelligence (information of specific value to users) to improve their cognitive structures. Different users absorb different intelligence, resulting in different cognitive structure improvements. New concept nodes in post-search concept maps reflect users' internalization of read text information into their own knowledge. Therefore, by comparing pre- and post-search concept maps and annotating new concept nodes, we manually coded the source documents and structural locations of concepts. Coding included two aspects: (1) whether new concepts came from the 10 documents users read; and (2) which part of the document structure the concept appeared in. A document's basic structure includes title, abstract, keywords, and full text. To avoid duplicate counting, each concept was assigned only one document structure attribute. According to cognitive load theory, the coding priority order was: title > abstract > keywords > full text. If a concept appeared in both abstract and full text, only the abstract was coded. If a new concept did not appear in any document and belonged to user-created vocabulary, it was coded as "self-summarized."

Through coding new concepts in concept maps, we can identify which text structures change user cognitive structures and reveal user-document cognitive interaction characteristics.

4 Experimental Results

4.1 Cognitive Structure Change Patterns and Characteristics

Based on the concept map quantitative evaluation system, we evaluated and compared pre- and post-search cognitive structures of 30 users, with results shown in Table 2 . S and S represent pre- and post-search concept map scores, respectively, and ΔS represents the score difference. The results show three score ranges: $3 < \Delta S < 7$, $12 < \Delta S < 37$, and $40 < \Delta S < 55$. Due to clear jumps between these ranges, they correspond to three cognitive structure change patterns: unchanged type, significantly improved type, and substantially improved type. While score differences and classification boundaries vary across experimental contexts without unified standards, in this experiment, 20 users (66.6%) showed significant cognitive structure improvement with differences between 10-40 points; 5 users (16.7%) achieved substantial improvement with differences above 40 points; and 5 users (16.7%) showed no significant improvement with differences below 10 points.

(1) Unchanged Type. Unchanged-type users had pre- and post-search concept map score differences between 3-7 points. Further statistical analysis of their six concept map indicators (Table 3) shows no significant differences in concept node richness, professionalism, effectiveness, or concept relationship connectivity, hierarchy, and exploratory nature ($P > 0.05$). This indicates no significant improvement in syntax, semantics, or pragmatics, with overall cognitive structure basically unchanged.

Figure 1 Figure 1: see original paper and Figure 1(b) show pre- and post-search concept maps from User U21. Pre-search cognitive structure mainly included concepts "rumor," "governance," and "social media," with classifications for "rumor" and "social media" and subcategories for "governance" including "characteristics and countermeasures," "solution," and "control." Post-search removed subcategories for "rumor" and "social media," focusing on expanding the "governance" node by changing "solution" to "governance approach" and adding subordinate nodes like "guide the public," "introduce foreign advanced experience," and "utilize objective communication laws" as professional expressions. Additionally, a new first-level concept node "network" was added but lacked subordinate nodes and could not accurately describe the theme. Overall, the pre-search concept map contained 2 levels and 12 connections, while the post-search map contained 3 levels and 10 connections, with hierarchy barely changed and only content expanded under one concept. Professionalism and effectiveness of concept nodes showed no significant improvement, with overall cognitive structure remaining basically unchanged.

(2) Significantly Improved Type. Significantly improved-type users had pre- and post-search concept map score differences between 12-37 points. Statistical analysis of their six indicators (Table 4) reveals significant differences between pre- and post-search concept map scores ($P < 0.05$). Specifically, concept node richness, relationship connectivity, and hierarchy show significant differences ($P < 0.05$), while concept node professionalism, effectiveness, and relationship exploratory nature show highly significant differences ($P < 0.001$). Compared with pre-search, richness and connectivity improved significantly by 85% and 88%, respectively. Post-search professionalism, effectiveness, and exploratory nature scores increased by over 100% (135%, 163%, and 169%, respectively). This indicates that this user type showed significant improvement in syntax, semantics, and pragmatics, with overall cognitive structure significantly improved.

Figure 2 Figure 2: see original paper and Figure 2(b) show pre- and post-search concept maps from User U2. Pre-search cognitive structure mainly included concepts "social media platform," "rumor," and "governance." Post-search maintained the same first-level concepts but added subordinate concepts, significantly increasing concept node richness. Content-wise, post-search added professional expressions related to "rumor" and "governance," such as "rumor types," "communication causes," "communication process," and "governance methods," which are closely related to the theme and significantly improved concept node professionalism and effectiveness compared with pre-search. Regarding concept relationships, the pre-search map contained 2 valid levels and 10 connections, while the post-search map contained 3 valid levels and 42 connections, with deeper hierarchy and richer relationships. The post-search map added specific subordinate concepts, improving concept node professionalism and effectiveness. Overall, the post-search concept map showed significant improvement compared with pre-search, reflecting a richer cognitive structure, though still incomplete with obvious deficiencies, such as using "governance" for both superior and subordinate concepts under "methods," requiring more precise vocabulary for clear expression.

(3) Substantially Improved Type. Substantially improved-type users had pre- and post-search concept map score differences between 40-55 points. Statistical analysis of their six indicators (Table 5) reveals highly significant differences between pre- and post-search concept map scores ($P < 0.001$). Specifically, concept node richness, relationship connectivity, and hierarchy show significant differences ($P < 0.05$), while concept node professionalism, effectiveness, and relationship exploratory nature show highly significant differences ($P < 0.001$). Compared with pre-search, richness and connectivity improved by over 100% (114% and 120%, respectively), while professionalism, effectiveness, and exploratory nature improved by over 180% (188%, 252%, and 280%, respectively). This indicates that substantially improved-type concept maps showed significant improvement not only in syntax and semantics but also very significant improvement in pragmatics, with users' overall cognitive structure substantially improved.

Figure 3 Figure 3: see original paper and Figure 3(b) show pre- and post-search concept maps from User U12. Pre-search cognitive structure mainly included concepts "social media types," "rumor," and "governance subjects and methods." Post-search changed "social media types" to "social media" and "governance subjects and methods" to "governance." Comparative analysis shows post-search added 44 nodes. Content-wise, the post-search concept map added theme-relevant concepts such as "communication mechanism," "comparison with traditional rumor governance methods," and "rumor characteristics," while also adding professional expressions from perspectives like "government," "regulatory departments," "social media operation platforms," and "users." The user summarized the theme "rumor governance in social media" into "problem front-end" and "problem back-end" aspects, with "problem front-end" including nodes related to "social media types" and "rumor," and "problem back-end" including nodes related to "governance," demonstrating novel and deep thinking about the theme and a more complete cognitive structure.

4.2 User-Document Cognitive Interaction Characteristics

Section 4.1 used changes in pre- and post-search concept maps to measure user cognitive structure changes ΔS. This section explores user-document cognitive interaction—how ΔI (intelligence absorbed by users) acts on $K[S]$ (user cognitive structure) to produce ΔS. Coding results for new concept nodes in post-search concept maps are shown in Table 6 . The unchanged group added 25 new concept nodes (average 5 per user), with 8 from document titles, 10 from abstracts, 3 from keywords, and 4 from full text. This indicates that this group's cognitive interaction focused on abstracts (39%) and titles (33%). No user-created new words appeared in this group's concept maps. In the significantly improved pattern, users added 426 new concept nodes (average 21.3 per user), with cognitive interaction primarily focusing on full text (63%), followed by abstracts (20%). This group added 31 new words (7%) that were user self-summarized (average 1.55 new words per user). In the substantially improved pattern, users added 209 new concept nodes (average 41.8 per user), with cognitive interaction focusing on full text at a higher proportion (69%), and 45 new words (22%) created through user self-summary (average 9 new words per user).

To further explore whether user-document cognitive interaction characteristics ΔI are closely related to user cognitive structure improvement ΔS and the correlation between user-document knowledge structure interactions, we conducted Pearson correlation analysis on six data points from 30 users. Results are shown in Table 7 . The analysis reveals that increased cognitive interaction with document titles, abstracts, and keywords does not significantly correlate with cognitive structure improvement, while increased cognitive interaction with document full text significantly positively correlates with cognitive structure improvement (correlation coefficient = 0.874, $p < 0.01$). Growth of self-summarized concepts in concept maps also significantly positively correlates with cognitive structure improvement (correlation coefficient = 0.790, $p < 0.01$). Moreover, increased cognitive interaction with full text positively correlates with growth of self-summarized concepts (correlation coefficient = 0.780, $p < 0.01$). These results suggest that user-document cognitive interaction with full text can enhance thinking depth and create more self-summarized concepts, with both improvements promoting cognitive structure refinement. These findings indicate that user-document cognitive interaction with full text is an important factor in improving cognitive structure.

Over the past decades, information retrieval research has primarily focused on the efficiency and effectiveness of indexing, retrieval, and ranking algorithms, hoping that continuous algorithmic improvements will achieve "delivering the right information to the right person at the right time." However, for most users, the ultimate goal of retrieval is not merely obtaining information but discovering new knowledge and improving their cognitive structures. This study's main objective is to test users' own cognitive structure changes before and after exploratory search—that is, whether and how much users' cognitive structures improve after searching. Results show that under conditions of identical theme, identical retrieval platform, identical reading time, and identical prior knowledge, users' cognitive structure changes before and after exploratory search present three patterns: two-thirds showed significant improvement, one-sixth remained unchanged, and one-sixth achieved substantial improvement.

If cognitive structure improvement represents learning outcomes, it must be influenced by the learning process. In exploratory search, users' learning processes involve both internal cognitive processes and external behavioral manifestations. While internal cognitive processes can be externalized through think-aloud methods, this approach interferes with users and some users are not adapted to such recording methods. Therefore, research focus has been placed on users' external interactions with systems. Many scholars have studied the relationship between search behavior and learning outcomes. C. Liu and X. Song [30] demonstrated that information recording significantly affects learning outcomes, with earlier information recording during search producing better learning outcomes. U. Gadiraju and R. Yu's team [17] found that users' dwell time on content pages significantly positively correlated with knowledge growth. However, in larger-scale research [31], the same team found only weak correlation between dwell time and knowledge growth. This study argues that the depth of user-document interaction is a key factor affecting knowledge structure changes, and that reading time alone cannot reveal interaction levels at a fine granularity. Some scholars have used eye-tracking to trace browsing trajectories, but this only reveals the low-level cognitive stage of what content users notice, not the high-level stages of memory, thinking, and imagination. As J. Gwizdka et al.'s [32] eye-tracking study found, users with higher learning outcomes actually read less than those with lower outcomes. This study examines user-document interaction from a new perspective—reflecting user-document cognitive interaction through literature structure information corresponding to new vocabulary in user-drawn concept maps. This perspective provides an important approach to revealing users' absorption and utilization of documents. Results show that users focusing on titles, abstracts, and keywords do not achieve ideal cognitive structure improvement, while reading full text to find new core concepts promotes cognitive structure improvement. This is because bibliographic information, though reflecting article main ideas, is limited by short length and may not be easily understood by novices, who can only remember isolated concepts without enriching their cognitive structures. Only through detailed full-text reading, discovering important concepts, correctly interpreting and understanding concept connotations, and building hidden connections between concepts can users truly improve cognitive depth. Therefore, user-document cognitive interaction with full text is an important factor in improving user cognitive structure.

According to Ausubel's learning theory [33], learners must establish substantial connections between knowledge absorbed from documents and existing cognitive structures to achieve meaningful learning. Substantiality is reflected in learners' ability to express concepts in different language forms (i.e., new words different from original text). These new concepts represent new knowledge produced through learners' subjective construction, indicating thinking has reached a higher stage. This study also confirms that growth of self-summarized concepts in concept maps significantly positively correlates with cognitive structure improvement. Therefore, user-created new vocabulary in concept maps can serve as an important indicator of knowledge structure changes.

Based on Brookes' fundamental equation of information science, this study explores patterns and characteristics of user cognitive changes before and after exploratory search and further analyzes how user-document interaction affects cognitive structure improvement. Results show that user cognitive structure changes present three patterns: 66.6% significantly improved, 16.7% remained unchanged, and 16.7% substantially improved. Specifically, the unchanged group showed no significant changes in concept node richness, professionalism, effectiveness, or relationship connectivity, hierarchy, and exploratory nature. The significantly improved and substantially improved groups showed significant changes in concept node richness, relationship connectivity, and hierarchy, and highly significant changes in concept node professionalism, effectiveness, and relationship exploratory nature.

This study further analyzed user-document cognitive interaction characteristics, revealing how different intelligence ΔI absorbed by users affects cognitive structure improvement ΔS. Results indicate that when users focus on bibliographic information, they remain at the physical interaction level, which does little to improve cognitive structures. Only through careful full-text reading, discovering other core concepts, and identifying complex relationships between concepts do users achieve deep cognitive interaction with documents, ultimately promoting cognitive structure improvement. Moreover, full-text cognitive interaction can enhance users' sense-making levels and help generate innovative vocabulary. Creating new associations through new concepts generates deeper, richer, and more flexible cognitive structures.

This study examined users' cognitive structure changes before and after searching under conditions of identical task difficulty, retrieval platform, prior knowledge, and learning time, and preliminarily explored how ΔI affects ΔS. Future research will expand user populations to investigate what knowledge structure change patterns users with different prior knowledge present and deeply explore the interaction mechanism between ΔI and K[S].

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Note: Figure translations are in progress. See original paper for figures.