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Metacognitive Performance of University Student Users in Exploratory Search: Postprint

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Abstract

[Purpose/Significance] To address the assessment of search metacognition among university student users in complex and multifaceted exploratory search contexts, a feasible and effective assessment questionnaire was designed. By establishing four distinct categories of exploratory search scenarios, participants' metacognitive performance in each specified context was subjected to multi-dimensional analysis and evaluation. [Method/Process] Drawing upon metacognitive theory, the "Exploratory Search Metacognition Assessment Questionnaire" was developed and its reliability and validity were examined during the pilot phase. In the formal assessment phase, 60 university student participants were recruited to conduct exploratory task searches and complete questionnaires through search tests, with their search screens recorded using "Camtasia Studio" and post-hoc interviews conducted. By synthesizing questionnaire data, search behavior videos, and interview content, an analysis was performed on participants' cognition of "search tasks and individual knowledge", "search process monitoring", and "search process and evaluation reflection" across the four different exploratory search contexts. [Results/Conclusion] The questionnaire exhibits good internal consistency reliability and construct validity, serving as an effective tool for assessing university student users' metacognitive level (or performance) in exploratory search. The dimensional data analysis reveals that university student users demonstrate relative deficiencies in individual capability cognition, task comprehension, and search obstacle monitoring abilities regarding decision-making problems (evaluative decision-making search) and research-oriented problems (knowledge acquisition search). Based on these findings, considerations and recommendations for improving university student users' exploratory search capabilities are proposed from three perspectives: university information literacy education, cultivation of search quotient, and human-computer interaction functional design of web search systems.

Full Text

A Study on the Metacognitive Performance of University Student Users in Exploratory Search

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Abstract: [Purpose/Significance] This study addresses the challenge of measuring university students' search metacognition in complex, multifaceted exploratory search contexts by designing a feasible and effective assessment questionnaire. Four distinct exploratory search scenarios were established to conduct multidimensional analysis and evaluation of participants' metacognitive performance under each prescribed context. [Method/Process] Drawing on metacognitive theory, we designed an "Exploratory Search Metacognition Assessment Questionnaire" and tested its reliability and validity during a pilot phase. In the formal assessment, 60 university student participants completed exploratory search tasks and questionnaires, with their search screens recorded using Camtasia Studio, followed by post-task interviews. Integrating questionnaire data, behavioral video recordings, and interview content, we analyzed participants' cognition regarding "search tasks and individual knowledge," "search process monitoring," and "search process evaluation and reflection" across four exploratory search contexts. [Result/Conclusion] The questionnaire demonstrated strong internal consistency reliability and structural validity, serving as an effective tool for assessing university students' exploratory search metacognitive levels. Dimensional analysis revealed that students showed relative deficiencies in self-cognition of ability, task comprehension, and search obstacle monitoring when facing decision-making problems (evaluation-decision search) and research problems (knowledge acquisition search). Based on these findings, we propose recommendations for improving university students' exploratory search capabilities from three perspectives: information literacy education, cultivation of "search quotient," and human-computer interaction design in web search systems.

1. Introduction

Today's internet users inhabit an information-rich, densely dynamic information space where the hierarchy of information needs escalates alongside increasingly multifaceted, complex, and dynamic problem situations. Traditional "question-answer" search models no longer suffice to maximize satisfaction of users' information needs in complex environments. Conventional information search theory assumes search goals are explicit, singular, and static, with the search process representing a basic interactive query procedure [1]. In contrast, exploratory search exhibits three key characteristics: First, it emphasizes continuous human-computer interaction and exploration throughout the search process, represent-

ing an exploratory activity interwoven with learning, investigation, and decision-making [2]. Second, users are unfamiliar with the search target domain, lack clear concrete search objectives, and are uncertain about pathways to achieve their goals [2]. Third, exploratory search results tend toward high personalization and openness. Users' actual search behaviors dynamically transform (e.g., selection and adjustment of search concepts, strategies, directions, and paths) as search goals are not always explicit, singular, or static. Clearly, exploratory search transcends traditional question-answer matching, aligning more closely with users' real-world search contexts.

The process of solving ill-structured exploratory search problems involves both cognitive and metacognitive components that play crucial roles [3]. While academic attention has focused primarily on users' cognitive performance in exploratory search—covering cognitive changes, patterns, and influencing factors—research on metacognitive aspects, which represent higher-level cognitive activities, remains scarce. Although some studies have examined metacognition in information seeking, relying solely on observable search behaviors proves insufficiently comprehensive. Quantitative measurement and analysis have become pressing issues. University students constitute a significant proportion of internet search users with diverse information needs, representing the mainstream group engaged in exploratory search activities [4]. However, existing research samples primarily comprise Western university students. Given differences in cultural atmosphere and student thinking patterns between East and West, empirical analysis of Chinese university student populations urgently needs expansion.

This study addresses this gap by using Chinese university students as research subjects, applying metacognitive theory to design an “Exploratory Search Metacognition Assessment Questionnaire.” Using the exploratory search process timeline as an axis and combining screen recording analysis with interview data, we conduct multidimensional measurement and analysis of users' search metacognitive performance across multiple open-ended problem scenarios, providing practical reference for future metacognitive research on exploratory search behavior.

2. Theoretical Overview

2.1 Exploratory Search Theory

As a research frontier emerging from the continuous subdivision of information behavior studies, exploratory search draws theoretical roots from numerous early information behavior models and concepts. Influential frameworks include M. J. Bates' Berry Picking Theory (emphasizing the “evolutionary” nature of search processes) [5], P. Pirolli's Information Foraging Theory (highlighting information seeking as movement between information patches) [6], and C. C. Kuhlthau's Information Search Process Theory (stressing behavioral, cognitive, and affective dimensions) [7]. G. Marchionini proposed that exploratory search

comprises two components: problem context and search process. Problem contexts are cognitively processed into information needs that drive search behavior, while the search process dynamically advances with users' multi-perspective and continuous information needs for ill-structured problems, exhibiting opportunistic, multi-strategic, and iterative characteristics [8]. R. White and colleagues subsequently developed a theoretical model reflecting interactions between problem context and search process [9], as shown in Figure 1 [Figure 1: see original paper].

This model demonstrates that search behavior unfolds along a timeline, progressing through alternating cycles of “exploratory browsing” (resource discovery, learning, investigation) and “focused searching” (query reformulation, information extraction, results verification). Transition points between these modes depend on users' evolving understanding and perception of the problem context throughout the search process. Regardless of which mode users experience, underlying physical behaviors are continuously regulated by higher-level perceptual activities.

2.2 Metacognition Theory

American socio-cognitive psychology founder J. H. Flavell first introduced the concept of metacognition in *Cognitive Development*, defining it as “cognition about cognition”—individual knowledge about their own cognitive processes and the ability to regulate these processes [10]. In subsequent research, Flavell expanded this concept into a theoretical model comprising metacognitive knowledge, metacognitive experiences, learning goals/tasks, and behaviors/strategies [11]. Domestic scholar Kang Zhonghe further proposed a university student metacognitive ability structure consisting of four capabilities: metacognitive planning, monitoring, regulation, and evaluation [12].

Information search represents a unified process of behavior, emotion, and cognition [13]. As a higher-level “cognition” in search activities, metacognition manifests as users' self-awareness, reflection, judgment, and regulation of search cognition. Research has demonstrated that metacognition influences both search behavior and outcomes [14], and its role becomes critically important in promoting and providing feedback throughout the search process when users confront complex, multifaceted ill-structured problem situations.

In summary, metacognition theory provides an effective lens for examining and evaluating users' abilities to monitor and regulate their search cognition across different exploratory search contexts.

3. Research Design and Implementation

3.1 Exploratory Search Task Design

Based on G. Marchionini's exploratory search task typology, we analyzed the characteristics of various search tasks from a functional perspective and selected

types that comprehensively cover students' routine search contexts: (1) **Planning Search**: Integrating fragmented information into actionable plans for future activities, emphasizing comprehensiveness and information integration, reflecting exploratory search's practical function. (2) **Knowledge Acquisition Search**: Oriented toward deeply learning a domain or tracking research developments, emphasizing depth and persistence, reflecting exploratory search's research function. (3) **Social Search**: Finding interest-based communities to obtain target information resource clues, reflecting exploratory search's social function. (4) **Evaluation-Decision Search**: Repeatedly reviewing, comparing, and evaluating documents to analyze similarities and differences among search targets for decision-making and problem-solving, emphasizing comparative processes, reflecting exploratory search's decision-making function.

B. M. Wildemuth's exploratory search task design principles emphasize: (1) simulating real-world work scenarios to create authentic task descriptions; (2) designing tasks that trigger dynamic and complex exploratory search behaviors; and (3) clearly presenting search scenarios with thematic openness and multiple targets [15]. Following these principles, we designed specific task instances as shown in Table 1 .

3.2 Exploratory Search Metacognition Assessment Questionnaire Design

3.2.1 Questionnaire Content Structure User task interpretation, self-perception of search ability, process management, and post-search evaluation/reflection constitute the entire search activity. To reflect process stage characteristics, the questionnaire structure comprises three main dimensions and nine sub-dimensions: pre-search metacognitive ability appears in the "Search Task and Individual Cognition" dimension; during-search ability in the "Search Process Monitoring Experience" dimension; and post-search ability in the "Search Process Evaluation and Reflection" dimension. Table 2 presents these dimensions and their definitions.

Using a five-point Likert scale, we developed the Exploratory Search Metacognition Assessment Questionnaire (see Table 3).

3.2.2 Reliability and Validity Testing To test the questionnaire's reliability, validity, and item appropriateness, we conducted a pilot study one week before formal testing. For data collection convenience, 73 university students were randomly selected as pilot participants to complete a "planning-type" exploratory search task (different from but within the same category as formal test tasks), answering all questionnaire items. Data were collected and analyzed immediately after task completion.

Validity Testing: Factor analysis assessed structural validity. We first conducted KMO and Bartlett's sphericity tests on main dimension data. Results showed all main dimensions had KMO values > 0.6 with significance levels of

0.000 (< 0.05), indicating item correlations suitable for factor analysis (see Table 4).

Using principal component analysis with varimax rotation, we grouped items with high matrix similarity to better interpret extracted factors. For the “Search Task and Individual Cognition” dimension, factor analysis of 11 items yielded three factors with contribution rates of 21.391%, 18.872%, and 17.280%, respectively, and a cumulative contribution rate of 57.543% ($> 50\%$), indicating good structural validity. Specific items per factor appear in Table 5.

For the “Search Process Monitoring” dimension, factor analysis of 8 items yielded three factors with contribution rates of 23.363%, 22.937%, and 22.020%, respectively, and a cumulative contribution rate of 68.321% ($> 50\%$), indicating good structural validity. Specific items per factor appear in Table 6.

For the “Search Process Evaluation and Reflection” dimension, factor analysis of 9 items yielded three factors with contribution rates of 21.392%, 20.245%, and 19.446%, respectively, and a cumulative contribution rate of 61.084% ($> 50\%$), indicating good structural validity. Specific items per factor appear in Table 7.

Reliability Testing: We used Cronbach’s alpha coefficients, with values > 0.6 indicating acceptable reliability. All nine sub-dimensions, including “Self-Cognition of Individual Ability,” “Self-Cognition of Search Task,” and “Self-Cognition of Search Strategy,” showed Cronbach’s alpha > 0.6 , demonstrating good reliability (see Table 8).

3.3 Research Implementation Process

3.3.1 Research Sample Selection Active exploratory search users primarily comprise highly educated university students. Therefore, we limited our sample to this population, focusing on graduate students and upper-level undergraduates who frequently engage in daily search activities, exhibit diverse information needs, and demonstrate strong adaptability to complex problem contexts. Given the complexity of large-scale search activities and the typical sample sizes (ranging from dozens to hundreds) in existing research, we recruited 60 graduate students and upper-level undergraduates with extensive web search experience. The sample maintained a 1:1 ratio of graduate to undergraduate students and a 1:1 gender ratio, representing majors in electrical engineering, computer control, educational technology, library science, and digital publishing.

3.3.2 Operational Procedure The test was conducted in December 2016 at the university’s central computer lab. Camtasia Studio screen recording software was installed and tested on each uniformly configured computer, with test documents uploaded for participant use. Participants received detailed explanations of test purposes and procedures, including test flow and screen recording software usage. The test comprised two phases: a warm-up session where participants completed a simple search task (the warm-up question in

Table 1) to acclimate and verify technical functionality, followed by the formal test.

During formal testing, participants completed two tasks: (1) four exploratory search questions with screen recording via Camtasia Studio, and (2) completion of the metacognition assessment questionnaire during search. No time limit was imposed; participants stopped when satisfied with results. Test administrators maintained order and distributed questionnaires.

Post-test, each participant underwent brief informal interviews. Research materials collected included 240 video files of search processes, 240 paper questionnaires, Word documents with search answers, and interview records.

4. Data Processing and Results Analysis

4.1 “Search Task and Individual Cognition” Across Different Exploratory Search Contexts

One-way ANOVA examined participants’ “search task and individual cognition” across task contexts. Results revealed significant differences in self-cognition of individual ability, search task cognition, and search strategy cognition ($p < 0.05$) (see Table 9).

Post-hoc comparisons for “self-cognition of individual ability” showed significantly higher mean scores for Task 1 and Task 3 versus Task 4. Participants’ mean score for Task 4 was 2.92 (< 3), indicating perceived search ability below moderate level. For “self-cognition of search task,” participants showed significantly higher cognition for Tasks 1 and 3 versus Tasks 2 and 4. For “self-cognition of search strategy,” participants demonstrated significantly higher strategy cognition for Tasks 1 and 3 versus Task 2.

4.2 “Search Process Monitoring” Across Different Exploratory Search Contexts

One-way ANOVA of “search process monitoring” revealed significant differences in overall process monitoring ($p < 0.05$) but not in obstacle monitoring or results monitoring ($p > 0.05$) (see Table 10).

Post-hoc comparisons for overall process monitoring showed highest scores for Task 3, followed by Task 4, with Tasks 1 and 2 scoring lowest. Participants’ monitoring experience in Task 3 was significantly better than in Tasks 1 and 2.

4.3 “Search Process Evaluation and Reflection” Across Different Exploratory Search Contexts

Analysis of “search process evaluation and reflection” showed no significant differences across task contexts in self-evaluation of query time consumption, browsing time consumption, or task completion ($p > 0.05$).

5. Research Conclusions

5.1 “Search Task and Individual Cognition” Performance

Before initiating search, participants’ self-cognition regarding search tasks and individual learning abilities constitutes essential metacognitive activity. When presented with open exploratory problem contexts, users initially struggle to define problems clearly, plan search goals and action steps, or identify multiple viable solutions. The preliminary task assessment phase involves mobilizing existing knowledge structures to understand information problems, comprehensively considering search targets, and making preliminary plans. This stage encompasses self-cognition of individual ability, search task cognition, and search strategy cognition.

Self-Cognition of Individual Ability: This dimension showed significant variation across tasks, particularly among planning search, social search, and evaluation-decision search tasks. Participants perceived higher search ability and stronger computer operation skills during planning and social search tasks. Additionally, 71.67% reported regular planning-related search needs, 70% frequently engaged in social search activities, while over half (58.33%) rarely or never used web search for evaluation-decision problems. This indicates greater dependence on web search for practical and social information needs, with correspondingly richer experience.

Self-Cognition of Search Task: Significant task-related differences emerged, with better task cognition for planning and social search tasks versus knowledge acquisition and evaluation-decision tasks. Regarding background knowledge, 70% were familiar with planning task contexts, 81.67% were familiar with social search contexts, while over half (53.33%) were unfamiliar with evaluation-decision contexts and 45% lacked domain knowledge for knowledge acquisition tasks. Participants also identified and locked onto search targets more effectively in planning and social search tasks.

Self-Cognition of Search Strategy: Significant differences appeared across planning, social, and knowledge acquisition tasks. Regarding search plan formation, 68.33% reported vague search strategies for knowledge acquisition tasks, with no attempt to conceptualize or plan searches.

5.2 “Search Process Monitoring” Performance

Search process monitoring involves perceiving and controlling both broad directions and detailed aspects of ongoing search activities to comprehensively manage progress and strategies, adjusting cognitive interests from multiple angles and degrees. This stage encompasses overall process monitoring, obstacle monitoring and response, and results monitoring.

Overall Process Monitoring: This dimension showed task-related differences among social search, knowledge acquisition search, and planning search

tasks. Participants reported the best overall monitoring experience during social search, superior to other tasks. Interviews revealed most participants experienced no information disorientation during social search, whereas disorientation increased during knowledge acquisition and planning tasks. Video analysis suggested two potential causes: (1) participants opened numerous webpages during planning tasks without orderly processing, and (2) during knowledge acquisition tasks, participants entered fewer queries with longer intervals, repeatedly performing “input-delete-reinput” operations, showing hesitation in query formulation and result selection.

Obstacle and Results Monitoring: No significant differences emerged across tasks for these dimensions. Overall mean scores indicated moderate obstacle monitoring and above-moderate results monitoring, suggesting participants maintained high alertness in monitoring search engine feedback, continuously assessing information quality and usefulness.

5.3 “Search Process Evaluation and Reflection” Performance

Post-search, participants primarily evaluated and reflected on search processes through perceived time consumption of important stages and overall task completion.

Time Consumption Evaluation: No significant differences appeared across tasks for query and browsing stage time consumption. However, comparison of mean scores (see Table 11) revealed participants spent more time browsing information, reflecting how exploratory search requires progressive browsing to enhance domain familiarity and comprehensively evaluate multiple targets before clarification. Query time consumption patterns were consistent across tasks, with increasing intensity in this order: selecting search tools, determining search terms, identifying search targets, and focused information searching (see Figure 2 [Figure 2: see original paper]). Participants primarily allocated query time to focused searching rather than platform selection. Behavioral analysis showed participants frequently navigated between multiple search portals, often accessing portals via current links rather than active selection, indicating this link-following approach is more common in exploratory contexts.

Task Completion Evaluation: No significant differences emerged across tasks. Regarding search time, environmental constraints enabled good time control. Task satisfaction was highest for social search tasks and lowest for knowledge acquisition tasks.

6. Discussion and Recommendations

6.1 Expanding University Information Literacy Education Content

Currently, most university information literacy instruction remains limited to library digital resources and retrieval methods offered by library institutions. The core of information literacy work involves developing users’ information

capabilities—including acquiring, synthesizing, analyzing, and evaluating information based on needs, as well as innovating upon existing information to generate new knowledge [16]. For university students, exploratory search dominated by learning and research plays a crucial role in knowledge discovery and creative thinking. Therefore, integrating exploratory search guidance and training into information literacy education is essential, emphasizing the cultivation of analytical, creative, and practical thinking skills for exploratory search, and developing higher-level information search capabilities.

6.2 Emphasizing “Search Quotient” Ability Cultivation

“Search quotient” represents an ability parallel to IQ and EQ [17]. Broadly defined, it encompasses the intelligence of all search behaviors; narrowly, it refers to the ability to use web search tools to locate needed information within massive, disordered online information [18]. In exploratory search, search quotient manifests not only as information search ability but also as learning ability, information association capacity, and the ability to monitor and regulate one’s own search activities. Search quotient is particularly critical in exploratory search tasks. Based on our findings, university students should enhance sensitivity to decision-making and research-oriented search problems: for decision-making problems, cultivate abilities to distinguish and evaluate similar information and form different solutions; for research problems, develop sustained tracking and in-depth learning of domain knowledge.

6.3 Expanding Web Search System Human-Computer Interaction Functions

To promote integration between information search behavior and self-directed learning and achieve high-level human-computer interaction in exploratory search, we recommend expanding relevant interaction functions: (1) **Real-time browsing process save/recall functionality**: Search systems should support temporary recording of previously browsed interest items during navigation, visually presenting them synchronously in the current interface to facilitate comparison and screening between current and past interests. (2) **Embedded “search monitoring” reminder functionality**: Search systems should intelligently provide “search monitoring” prompts based on users’ current search contexts and behavioral history data to promote regulation and monitoring of search cognitive activities for better problem-solving and search experiences.

Limitations and Future Directions

This study has limitations in sample coverage and quantity, and the test environment inevitably contained distracting factors. Future research will expand test scope and refine study design.

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Abstract: [Purpose/Significance] This paper develops a feasible and effective questionnaire for the metacognitive measurement issues of university students in multifaceted and exploratory search situations. It designs four different types of exploratory search situations and conducts multi-dimensional analysis and evaluation of subjects' metacognitive performance under each prescribed situation. [Method/Process] In this paper, we used metacognitive theory to design an "exploratory search metacognitive assessment questionnaire" and conducted its reliability and validity test in a pilot study. Additionally, by conducting a search test, we selected 60 university students to conduct exploratory search tasks and gave them a questionnaire in the formal evaluation process. In this process, we also used Camtasia Studio to record search images and conducted a post-interview. Through survey data, search behavior videos, and interviews, we analyzed users' cognition of search tasks and self-cognitive, search process monitoring, and search process evaluation in four different types of exploratory search situations. [Result/Conclusion] On the one hand, the questionnaire has a good coefficient of internal consistency reliability and validity, and it can be used as an effective tool to measure university students' exploratory search metacognitive level (or performance). On the other hand, according to the dimensional data analysis result, university students' self-cognitive, task comprehension, and search obstacle monitoring capability are relatively less when faced with decision-type problems (evaluation decision search) and research problems (knowledge acquisition search). According to the results, we propose suggestions to improve university students' exploratory search abilities from three aspects: information literacy education, cultivation of SQ, and human-computer interaction function of web search system.

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

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