Research Advances in Exploratory Search: Post-print

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Abstract

[Purpose/Significance] To analyze the research status and development trends of exploratory search, so as to promote academic and application innovation in this field. [Method/Process] Using literature review and comparative analysis, this paper introduces the research overview of exploratory search both domestically and internationally from three aspects: conceptual research, process research, and theoretical research, and conducts a critical review from four dimensions: research content, research object, research method, and research conclusion, including research on influencing factors of exploratory search, search result optimization, and exploratory search system construction. On this basis, it prospects the research trends of exploratory search. [Results/Conclusion] In the big data environment, exploratory search will develop along the direction of multi-technology integration and cross-device search. In terms of research methods, mixed methods combining quantitative and qualitative approaches have become mainstream; in terms of research content, exploratory search with multi-technology and cross-device integration, learning mechanism research of exploratory search, and collaborative exploratory search are future feasible and highly valuable hot research topics.

Full Text

Research Progress in Exploratory Search

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Abstract: [Purpose/Significance] This paper analyzes the research status and development trends of exploratory search to promote academic and application innovation in this field. [Method/Process] Using literature review and comparative analysis methods, we introduce the research landscape of

exploratory search both domestically and internationally from three perspectives: conceptual research, process research, and theoretical research. We then review these from four dimensions: research content, research object, research method, and research conclusion, covering studies on influencing factors of exploratory search, search result optimization, and exploratory search system construction. Based on this analysis, we prospect future research trends. [Result/Conclusion] In the big data environment, exploratory search will develop toward multi-technology integration and cross-device search. In terms of research methods, mixed methods combining quantitative and qualitative approaches have become mainstream. Regarding research content, multi-technology and cross-device exploratory search, learning mechanism research in exploratory search, and collaborative exploratory search represent promising and valuable future research topics.

Keywords: exploratory search; user behavior; research overview; development trends

1 Introduction

The rapid development of the Internet has made information search behaviors more diverse and flexible, raising an urgent question: "Are current search technologies sufficient to meet all user needs?" Traditional information retrieval models match query expressions with documents stored in retrieval systems to return relevant results for users. However, in most real-world situations, users' information needs are ambiguous. When users do not know how to search, they cannot formulate appropriate query expressions in one attempt, making such lookup-based information retrieval models inadequate. Since the 1990s, traditional search methods have failed to reflect the process of user-system interaction, nor can they capture how information needs change during search or how contextual factors influence the search process [1]. To address this issue, G. Marchionini proposed a new information search paradigm—exploratory search [2], which better reflects the uncertainty and dynamic changes in information needs and objectively represents human-computer interaction behaviors.

Research on exploratory search began with the "Exploratory Search Interfaces" workshop held at the University of Maryland in 2005 [3]. Subsequently, in 2006, the Association for Computing Machinery (ACM) published a special issue on exploratory search, and ACM has since hosted multiple workshops on "Exploratory Search and Human-Computer Interaction" and "Evaluation of Exploratory Search Systems." These discussions have made exploratory search a hot research topic in information-seeking behavior. The concept of "exploratory search" has enabled more in-depth research on complex information search problems in the network environment. When users are unfamiliar with a target domain or uncertain about their search objectives, they often need to conduct multiple tentative searches to achieve their retrieval goals. To meet people's growing information needs and provide them with more efficient retrieval tools, studying the patterns and characteristics of exploratory search, optimizing search

processes, and constructing search systems to support efficient user search have important academic and practical significance.

Compared with foreign research, China's research on exploratory search started relatively late and has a weaker foundation. While foreign research is relatively concrete and complete, most domestic research has focused on theoretical studies, primarily addressing the characteristics and influencing factors of exploratory search. This paper reviews the research landscape of exploratory search from four dimensions—research content, research object, research method, and research conclusion—identifies current research limitations, and proposes suggestions for future research to provide references for subsequent studies.

2 Literature Sources and Research Approach

2.1 Literature Acquisition Principles To ensure data accuracy, objectivity, and reliability, we performed meticulous work in selecting data sources, determining search terms, and filtering methods:

2.1.1 Strict Limitation of Literature Types

Only research literature (journal articles, conference papers) was selected, excluding non-research literature such as news and policy documents.

2.1.2 Strict Control of Literature Quality

For Chinese literature, priority was given to CSSCI-indexed documents; for English literature, SSCI and SCI-indexed documents were prioritized, with comprehensive consideration given to journal impact factors, citation rates, and author research levels.

2.2 Literature Acquisition Process Research on exploratory search behavior started relatively late in China, making English literature more reflective of current research hotspots and frontiers. Therefore, this study primarily uses English literature supplemented by Chinese literature. The search period was set with no start date limitation and an end date of January 30, 2019.

For English literature, we selected four authoritative databases (WoS, Emerald, Wiley, and ACM) and used "exploratory search," "exploratory retrieval," and "exploratory seeking" as search terms in the "topic" field, retrieving 337 relevant papers. Strictly adhering to the above principles and ensuring literature relevance, we reviewed article titles and abstracts to exclude less relevant papers and conducted backward searches through references, ultimately selecting 42 English documents. For Chinese literature, we used CNKI, Wanfang, and VIP databases with search terms including "探索式搜索" (exploratory search), "探寻式搜索" (exploratory search), "探索式搜寻" (exploratory seeking), and "探索式查找" (exploratory lookup), retrieving 23 relevant documents. After manual screening and backward searches, we obtained 17 Chinese documents.

2.3 Research Framework This paper first 梳理 s the knowledge 脉络 of exploratory search from three aspects: conceptual research, process research, and theoretical research. Conceptual research introduces the background and definition of exploratory search; process research summarizes an exploratory search process diagram based on its characteristics; theoretical research further describes how the berrypicking model, information foraging model, and interactive information search model have influenced and promoted the development of exploratory search. The study finds that current exploratory search research has moved beyond mere perception and description, with increasing scholars designing reasonable user behavior experiments to discover and reveal the characteristics and patterns of exploratory search. User experiments typically include four components: research content, research method, research object, and research conclusion, with research content including research topic analysis. Therefore, this paper reviews exploratory search from these four dimensions.

3 Overview of Exploratory Search Research

3.1 Conceptual Research on Exploratory Search The definition of exploratory search is complex and multifaceted. To some extent, any information need and actual search behavior has exploratory properties. Before the concept of exploratory search was proposed, relevant research had already discussed information-seeking behavior and its exploratory nature. T. D. Wilson [4] argued that information-seeking behavior is caused by uncertainty, which stems from problems people face, and that the essence of information search behavior is to solve problems and eliminate uncertainty. In information search process models, C. Kuhlthau [5] mentioned that uncertainty gradually decreases as understanding increases. R. W. White et al. [6] believed that exploratory search is often driven by complex information problems and poor understanding of terminology and information space structure. This problem-context-induced uncertainty accompanies the entire search process. Searchers typically need to submit a tentative query to select the most relevant documents, then explore the context to better understand and utilize it, and selectively seek while passively acquiring cues for subsequent steps. As the search process deepens, uncertainty continuously decreases. Thus, exploration runs through the entire information-seeking process.

G. Marchionini [2] defined exploratory search as a unique-answer-free, persistent, multifaceted information-seeking process with uncertain problem context and direction, involving multiple cycles and tactics, and emphasized that exploratory search is particularly relevant to learning and research activities. Current search engines, bibliographic databases, and digital libraries can provide adequate query services for users with clear information needs, but when users lack knowledge or situational awareness and struggle to formulate queries, search systems find it difficult to meet their needs [7]. Compared with traditional "question-answering" information retrieval models, exploratory search involves fuzzy and uncertain information needs and expressions at the initial stage. Solv-

ing fuzzy or complex information problems requires exploratory search. People engaged in exploratory search typically: (1) have unknown or partially unknown search goals; (2) start searching from known content that becomes unknown or unfamiliar when encountering new information. After solving the search problem, users' knowledge level and understanding ability improve. Exploratory search is generally considered a user-challenging search activity centered on "user acquisition of new knowledge" [8]. Exploratory behavior includes not only exploratory search but also complex cognitive activities related to knowledge acquisition and skill development.

3.2 Process Research on Exploratory Search Exploratory search is driven by problem contexts. As topic familiarity and user knowledge increase, users collect information and re-represent it, reducing inherent uncertainty in the problem context [9]. Factors triggering exploratory search can be summarized as information needs, uncertainty, ill-structured information, tasks at hand, curiosity, etc. [1]. During exploratory search, searchers' information needs evolve from initially fuzzy states to known and understood states. In this process of information need development, searchers' ability to express queries and identify relevant information improves as their problem understanding level increases, helping them make more informed decisions. Throughout this process, searchers' knowledge levels change, demonstrating "learning" characteristics. Exploratory search driven by personal curiosity or learning desire better reflects this learning feature. Yuan Hong et al. [10] established a comprehensive exploratory search learning behavior index and summarized a three-stage individual learning model, identifying three stages in the search process: basic knowledge learning, thematic content learning, and interest-based specialized learning. To study changes in knowledge level before and after searching, Song Xiaoxuan et al. [11] used user experiments to evaluate knowledge content written by users before and after searching, proposing a user knowledge assessment method integrating quantity and quality dimensions. Results showed significant improvements in both the quantity and quality of user knowledge.

Exploratory search processes are accompanied by learning. Two main activities exist in exploratory search processes: exploratory browsing and focused searching [8]. Exploratory browsing primarily involves browsing documents related to search problems during the search process and further exploring viewed documents to promote information discovery. Through this approach, browsing includes behaviors such as initiating, sampling, selecting, reading, and stopping, which are iterative and repeated during the search process [12]. Focused searching typically involves a series of navigations to help users follow known or anticipated paths. During the search process, users query relevant document sets, browse results and documents near search results, and extract relevant information to achieve search goals. Exploratory browsing and focused searching demonstrate the iterative, multi-tactical, and dynamic characteristics of exploratory search processes. Searchers need to analyze, eliminate, and evaluate

search results while continuously conducting query transformations to predict and support subsequent search results. Based on analysis of existing research, the exploratory search process is summarized in Figure 1 [Figure 1: see original paper].

3.3 Theoretical Research on Exploratory Search The theoretical roots of exploratory search can be found in information retrieval, information behavior, and human-computer interaction fields. Under traditional information search modes, theoretical research on exploratory search behavior mainly follows the main line from search strategies and human-computer interaction to the integration of context and cognition. Representative theories of search strategies include the berrypicking model, while representative theories from a human-computer interaction perspective include information foraging theory. Both theories start from users' external behaviors, while interactive information retrieval models incorporating emotion and cognition compensate for the lack of research on internal behaviors in exploratory search.

(1) Berrypicking Model
In 1989, M. J. Bates proposed the berrypicking model [7], introducing "evolutionary search" theory for classic information retrieval models. Unlike traditional question-answering retrieval modes, evolutionary search theory identifies two characteristics of real-world searching: (1) users' query expressions continuously change, and new information encountered during the search process brings new ideas, causing dynamic evolution of users' information needs; (2) information need satisfaction is not achieved through a set of optimal search results. At each search stage, users collect some useful information, and linking this information together achieves the overall retrieval goal. M. J. Bates' berrypicking model emphasizes that browsing and navigation without clear tasks can also serve as an information-seeking mode.

(2) Information Foraging Model
The main idea of the information foraging model originates from optimal foraging theory proposed by anthropologists and biologists to explain how animals find food. Information foraging theory focuses more on the evolutionary process of search activities themselves. Users need to achieve an optimal balance between time, money, and effort spent and information obtained, assuming that human adaptive success largely depends on strategies for complex information gathering, sense-making, decision-making, and problem-solving. The information search process presents the following characteristics: sequentially identifying and selecting information patches, conducting focused searches through queries, tracking information scent emitted by information objects to move from one patch to another for exploratory browsing, and ending search behavior based on result satisfaction. Both the berrypicking model and information foraging model emphasize that information search is a sequential development process and simultaneously a cross-combination of focused searching and exploratory browsing [1].

(3) Interactive Information Search Model
Interactive information search models no longer limit their perspective to the system itself but focus more on the interaction process between users and systems. Interactive behaviors affect users' cognitive states, thereby influencing search results. In 1991, C. C. Kuhlthau proposed the information search process model, whose most significant feature is demonstrating the interaction among behavior, cognition, and emotion [5]. On this basis, in 1995, G. Marchionini's information-seeking process model considered the interaction between information tasks and environmental factors and their impact on the systematic and serendipitous nature of the information-seeking process [14]. In 2007, P. Ingwersen et al. integrated a holistic cognitive approach and proposed an interactive search cognitive framework [15]. These models consider not only user-system interaction behaviors but also the impact of context and cognition on search behavior.

These theories all have explanatory power for exploratory search. The berrypicking model and information foraging model mainly emphasize searchers' external behaviors—the influence of the information environment on search—while interactive information retrieval models focus on searchers' internal behaviors, such as the impact of cognition and motivation on search. These theoretical models provide important impetus for the theoretical development of exploratory search but do not fully reflect the "exploratory" characteristics of the search process. With the development of human-computer interaction and information retrieval research, theoretical research on exploratory search will gradually improve.

4 Research Dimensions

4.1 Dimension One: Research Content Through literature review, we found that research purposes mainly concentrate on three aspects: influencing factors of exploratory search, search result optimization, and exploratory search system construction. Research on influencing factors can theoretically deepen understanding of exploratory search behavior patterns and characteristics, providing references for building exploratory search behavior models, and practically help establish and improve exploratory search systems. Search result optimization can help users form more precise query expressions and obtain search results through the shortest path during the search process. Finally, the tools and means for users to achieve exploratory search require building exploratory search systems.

4.1.1 Research on Influencing Factors of Exploratory Search
Research content focuses on "what are the influencing factors of exploratory search" and "what impacts they produce." Through literature review, we found that influencing factors of exploratory search are mainly manifested in four aspects: user cognition, emotion, search tasks, and search ability. Research questions mainly include: (1) How do user cognition and search result satisfaction influence each other? (2) What are searchers' cognitive changes and transformation processes during exploratory search? (3) How does emotion affect the

exploratory search process? (4) What are the impacts of user search ability and task type on exploratory search behavior?

4.1.2 Research on Search Result Optimization

Due to the complexity of exploratory search tasks involving various search activities at the action, tactic, and strategy levels, numerous studies aim to provide methods for optimizing search results during exploratory search processes. During search, there are many instances of search goal shifting. In response, many studies propose query recommendation methods, dynamically predict and recommend search paths, and finally filter, classify, and rank search results. Research on search result optimization mainly focuses on three aspects: (1) optimizing search strategies; (2) personalized recommendation and prediction of search processes; (3) search result filtering.

4.1.3 Research on Search System Construction

With the continuous development of exploratory search theory and exploration of search result optimization methods, how to build systems supporting exploratory search has become a research hotspot. Due to the exploratory and uncertain nature of exploratory search backgrounds and processes, compared with traditional information retrieval systems, current exploratory search systems' main functional characteristics are: (1) supporting query formulation and rapid query optimization, helping users adjust and customize query expressions; (2) providing visualization support for search, offering visual representations of search collections; (3) classifying and ranking search results to reduce information space density and highlight key information.

4.2 Dimension Two: Research Object Experimental research on exploratory search behavior follows the basic principles of behavioral science research, with the primary task being the selection of experimental subjects. Table 1 lists the basic characteristics of research subjects recruited for exploratory search behavior experiments. Overall, researchers mainly consider demographic variables (including gender, age, educational background) and personal characteristics (including information literacy, retrieval ability) when selecting subjects. Researchers control the gender ratio at approximately 1:1 to eliminate gender effects on experiments. To ensure adequate data, the average number of participants is about 35. Subjects' educational backgrounds are mainly undergraduates and graduate students, with selections from both different and same professional backgrounds. Considering that exploratory tasks are typically difficult, researchers usually screen subjects with certain information literacy and retrieval abilities through questionnaires before experiments, dividing them into high-score and low-score groups based on information retrieval ability test results.

Researchers do not objectively explain the reasons for controlling various independent variables and conducting divisions, such as age, gender distribution, and number of groups. We believe that further explanation of the basis for control and division would help improve the credibility of experimental results

and increase external validity. Current subject selection largely targets university students and researchers, with less research on specific groups such as those with lower education levels or older adults. Studying search behavior patterns of different groups is important for improving search efficiency for specific populations.

4.3 Dimension Three: Research Method We adopt the research method system of user information behavior to construct the exploratory search behavior research method system, dividing it into three aspects according to different research content types: influencing factors of exploratory search, exploratory search result optimization, and exploratory search system construction, as detailed in Table 2 .

Quantitative research, qualitative research, and mixed-methods research are commonly used methods in current social science fields [33]. Through literature review, we found that current exploratory search behavior research mostly abandons single methods in favor of mixed-methods research. Overall, "questionnaire survey + experiment + log analysis" is the main research method for exploratory search behavior. In influencing factors research, most scholars use "questionnaire survey + interview + log analysis"; in search result optimization research, "simulation experiment + log analysis" has become the main method combination; in system construction research, "questionnaire + simulation experiment + log analysis" is most frequently used. Overall, quantitative methods account for a larger proportion in mixed-methods research, while observational and think-aloud methods are less used in qualitative methods. Through comparison, we can see that with deepening exploratory search behavior research, participants' behavioral performance and search details receive increasing attention, with eye-tracking, screen recording analysis, and think-aloud methods gradually gaining importance.

From the perspective of intervention, intervention refers to whether research subjects are disturbed by the research itself during data collection [34]. Questionnaire, interview, and experiment methods widely used in exploratory search research are typical intervention methods, while non-intervention methods include observation, think-aloud, and log analysis in non-experimental environments. Users' search behavior may be affected by the experimental environment to some extent, producing Hawthorne effects. Therefore, we believe future research should adopt more non-intervention methods to avoid or reduce external intervention, which helps weaken observer effects and eliminate observer bias. Thus, exploratory search behavior research methods will develop toward mixed-methods trends.

4.4 Dimension Four: Research Conclusion We summarize existing research conclusions from three aspects: influencing factors research, search result optimization research, and search system construction research. Influencing factors research is theoretical, while search result optimization and system

construction research are practical.

4.4.1 Conclusions on Influencing Factors of Exploratory Search

These include: (1) In cognition, cognition is divided into goal cognition, knowledge cognition, difficulty cognition, and search cognition [16]. User cognition significantly affects search result satisfaction, with goal cognition and knowledge cognition positively influencing satisfaction, while search cognition and difficulty cognition negatively influence it. (2) In emotion, emotion is divided into positive and negative emotions. As search task complexity increases, negative emotions show a concentrated trend compared to positive emotions, with emotional changes showing stage characteristics. Among negative emotions, anxiety affects some process variables in exploratory search. Anxious searchers show relatively dispersed attention during search, tending to reduce search times to complete searches faster, thereby affecting search result satisfaction [16]. (3) In search tasks, as task complexity increases, users' search behaviors become more in-depth and open, with closer connections between search results [17, 19]. (4) In search ability, stronger search ability leads to deeper, broader, and more efficient searches [18]. However, search ability has less impact on exploratory search than search tasks, though it significantly affects search behavior and fixation frequency, with little impact on fixation duration. Specifically, there are no significant differences in the number of browsed pages, frequency of search term usage, and browsing time [20]. However, high-ability subjects use more accurate and unified initial search terms and conduct more in-depth and extensive search processes.

4.4.2 Conclusions on Exploratory Search Result Optimization

These include: (1) In optimizing search strategies, Z. Carevic et al. [24] found through user surveys that the most common search strategy is keyword search, followed by browsing references and citations and author search. To enhance keyword search, J. Waitelonis et al. [44] demonstrated how to use linked open data to promote exploratory semantic search of video data. Addressing insufficient interaction and poor results, P. Paradakos et al. [31] proposed a method allowing users to gradually limit their focus using static and dynamically mined metadata. (2) In prediction and recommendation, H. Sun et al. [37] proposed a topic-oriented exploratory search method to provide browsing guidance and promote discovery of new associations and knowledge, helping users find interesting information. When searching, users may need help beyond query suggestions. C. Hendahhewa et al. [25] proposed a search path recommendation method using search process prediction models to evaluate user performance and recommend search trails based on similar users' behaviors, showing that recommended search path sequences are superior to random sequences and improve overall search efficiency. C. Ma et al. [45] used machine learning methods to extract all query terms from search engine logs to construct search goal shift graphs based on user behavior characteristics during goal shifting, finally obtaining query suggestions through random walk algorithms. Most information retrieval systems ignore the basic processes of information search. C. Shah et al. [39] dynamically evaluated and predicted search performance at each time

point in the search process through machine learning methods. (3) Search result filtering is mainly achieved through classification and ranking. In exploratory search pages, search results are usually returned in relevance ranking order. C. D. Sciasscio et al. [36] introduced an interactive user-driven tool that brings lower cognitive load to users compared with traditional ranking methods. In classification methods, P. M. Herceg et al. [38] proposed an exploratory search strategy to help professional information searchers effectively classify all data, reducing large amounts of information into a manageable, high-precision dataset.

4.4.3 Conclusions on Exploratory Search System Construction

These include: (1) In optimizing query expressions, O. Hoeber et al. [43] developed WordBars to provide valuable support for query optimization and search result exploration during Web search and exploration tasks. M. Schraefel et al. [46] proposed the mSpace interaction model and software framework, which improves information access through multiple support methods. S. Lu et al. [26] developed a system allowing seamless switching between browsing and searching to naturally complete visual exploratory search tasks. R. Singh et al. [29] provided a new representation interaction paradigm for exploratory Web search, allowing simultaneous presentation of query results from different semantic perspectives. (2) In search set visualization, J. W. Ahn et al. [32] proposed integrated interactive visualization and specific methods for personalized search, introducing the visual search system VIBE. H. Kai et al. [47] designed the Picass system, demonstrating progressive visualization, incremental query processing, and multi-stream result exploration wall characteristics, providing possibilities for visualizing, exploring, and analyzing search results.

5 Summary and Outlook

5.1 Research Summary Current exploratory search research still has some limitations. In research content: (1) Regarding theoretical research, exploratory search theory draws on related information search behavior theories but has not yet formed a clear theoretical framework. Experimental environment behavior research mainly focuses on certain resources or domains and has not constructed behavioral models in real contexts to develop universal models. (2) Current influencing factor research mainly approaches from the perspectives of "people" and search tasks themselves, without considering demographic characteristics, different education levels, and information literacy factors. Exploratory search behavior belongs to human-computer interaction behavior and should also consider computers and external information environments, such as information source selection, retrieval system page design, and social environment impacts. (3) Current exploratory search systems usually provide only one interaction mode, while users may need multiple interaction modes for exploratory search. Beyond being search tools, exploratory search is an activity accompanied by learning and research behavior, so system construction should consider system enjoyment and attractiveness to better improve users' knowledge levels and understanding abilities.

In research methods, mixed-methods research remains mainstream. Exploratory search behavior is not a simple linear activity; it involves complex emotional and cognitive changes with many uncertain factors. Structured data collection methods require pre-assumptions about research objects, and slight deviations affect experimental data validity. Semi-structured or in-depth interview data collection methods can effectively ensure data reliability and authenticity. Descriptive research on exploratory search exceeds explanatory research. Quantitative methods usually produce descriptive conclusions that can describe relationships and characteristics between phenomena but rarely reveal causal relationships. Qualitative methods such as observation, think-aloud, and group discussions can further discover behavioral patterns and characteristics of exploratory search.

5.2 Research Outlook Through analysis of current research, exploratory search research has made significant progress but still has research gaps for future reference. From the perspective of information technology development trends, in multi-device and multi-technology environments, users' information search behaviors will become more diverse, generating large amounts of user behavior data. From the characteristics of exploratory search itself, the exploratory search process is also a user learning process. How to optimize search processes to promote user knowledge acquisition is worth discussing. Here, we boldly predict future development directions for exploratory search research.

5.2.1 Multi-Technology and Cross-Device Exploratory Search Research

Technological advances in virtual reality and mobile devices create numerous opportunities for exploratory search systems. The diversification and increasing number of user search devices make cross-device searching a trend. Users' search activities are interrupted by external environments and device functions, causing them to switch to other search devices [48]. With changing interests and query expressions, how to help users efficiently conduct human-computer interaction in multi-technology fusion environments will become one of the future research directions for exploratory search.

5.2.2 Big Data-Driven Exploratory Search Research

With the maturation of big data technology, a data-centric research paradigm for user information behavior has formed. Different environments and devices generate large amounts of behavior data. Using data mining techniques to analyze behavior data, discover exploratory search behavior patterns, and support system development will be possible. Big data-driven approaches can utilize other users' search behaviors in information spaces to provide similar search paths and related documents for users, making searches more convenient and bringing more precise recommendation services and predictive support for users conducting exploratory searches in unknown domains.

5.2.3 Learning Mechanism Research in Exploratory Search

The exploratory search process is also a process of user knowledge construction and innovation. Yuan Hong et al. [10] explored the correlation between

search behavior and learning behavior, constructing relatively comprehensive exploratory search behavior and learning behavior indicators. We believe that beyond evaluating learning effect indicators, learning-oriented search behavior cannot ignore the impact of emotional factor changes on learning effects. Therefore, analyzing learning mechanisms from emotional and cognitive perspectives needs strengthening.

5.2.4 Collaborative Exploratory Search Research

Exploratory search is not always an individual activity. Multi-topic exploratory tasks often involve multiple participants, and collaborative exploratory search can complete search tasks more efficiently. Additionally, current research focuses more on individual exploratory search activities, ignoring that interpersonal information exchange may run through the entire information search process, with little mention of social interaction's impact on exploratory search. In the era of information explosion, seeking help from others is increasingly common, and information exchange between users is more frequent. Research on social support for exploratory search needs more attention.

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Author Contributions

Xia Lixin: Conceptualization, research design, revision suggestions.
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Note: Figure translations are in progress. See original paper for figures.