Searching the Literature: An Analysis of an Exploratory Search Task

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ABSTRACT

Exploratory search is an intuitive concept in interactive information retrieval. While many definitions for Exploratory Search have been proposed, the main dimensions involve high uncertainty with respect to the problem context, the user expertise, and the search process. In this paper, we draw together the different characteristics relating to the three main exploratory dimensions to provide a conceptual model of exploratory search. We build an exploratory search questionnaire using this model. We then use the questionnaire instrument to examine how literature searches are exploratory and what factors influence the exploratory dimensions and characteristics. We provide one of the first detailed investigations into the nature of exploratory literature review searches. Our analysis of the 368 responses reveals that about 84% of the participants described their literature review task as somewhat exploratory or very exploratory in nature. Also, the analysis points to another dimension of the exploratory search, the knowledge gain/change dimension. Furthermore, we investigated how users' experience influences how people rate the exploratory search characteristics (e.g., whether they find surprising information, learn new concepts and keywords).

CCS CONCEPTS

• **Information systems → Search interfaces**.

KEYWORDS

Exploratory Search, Exploratory Model, Literature Search, Information Seeking and Retrieval

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1 INTRODUCTION

Searching the literature to find relevant references for a report, a thesis or a publication is typically considered an exploratory search task by the Information Seeking and Retrieval community [13, 19, 26, 32]. Such work tasks often involve employing various search tools, techniques, and methods to find the relevant information. Moreover, it is usually performed over time and in an ad-hoc manner where searchers tentatively explore the domain to learn about their topic –generally referred to as using exploratory search strategies [13, 19, 32].

Various researchers have offered different ways to characterise how exploratory a search task is, the main dimensions of exploratory search, and what factors make a search exploratory within each of its dimensions. According to White et al. [35], exploratory search can be used to describe an information-seeking problem context that is an open-ended, persistent, and multi-faceted, and an information-seeking process that is opportunistic, iterative, and multi-tactical. Based on White & Roth [36], the main characteristics of users who engage in exploratory searches are: A lack of knowledge or familiarity about a particular topic/domain; a lack of certainty about their precise goals, and; a lack of certainty in how the user will achieve their information-seeking goals. Kules & Capra [22] suggest operational characteristics for exploratory search tasks, where answers are not found on the first interaction, users interact with the results and/or reformulate their queries, and users search for multiple items.

Wildemuth & Freund [37] reviewed previous studies related to exploratory search and concluded that the main characteristics of the exploratory search tasks are: general, open-ended, focus on learning and investigative search goals, and often target multiple items/documents. For Wildemuth & Freund, exploratory search tasks involve uncertainty, and are motivated by ill-defined or ill-structured problems. Additionally, exploratory search tasks are dynamic, multi-faceted, complex, and often accompanied by other information or cognitive behaviors, such as sense-making [37]. However, the literature has little consensus about what exploratory search actually means and what are its main dimensions and definitions.

Although many researchers in the Information Seeking and Retrieval community used conducting a literature review as a tool to study exploratory search, interestingly, in other literature, it is often considered a much formal, well-defined, and structured process with a clear goal [7, 29]. Some researchers in the Information Seeking and Retrieval field tried to formalise this intuitive and high-level understanding of the exploratory search more precisely. For example, Nedumova & Kuznetsov [26] examined which scientific search tasks can be classified as exploratory search ones. Also, Athukorala et al. [2] tried to formalise a model to estimate the subjective specificity in exploratory search by observing the behavior of computer science researchers exploring the literature. Shukla &

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Hoeber [32] assumed that academics employ exploratory search strategies when searching for literature on a new topic. However, there is a lack of empirical studies on exploratory search behaviors, and the literature lacks empirical evidence supporting the claim that reviewing the literature is an exploratory search task.

Basically, when trying to classify search tasks, it often devolves into a binary classification; if it is not a known-item search, it is exploratory [23]. However, the search task could be exploratory in one dimension or many. A highly exploratory search task is when the *user* is very unfamiliar with the topic or the *problem context*, very uncertain about the *process*, and highly uncertain about the goal. On the other end of the spectrum, and in direct contrast to exploratory search, is known-item search, in which the user knows the topic, knows the item that they are looking for, and knows how to get it. The literature is unclear about the driving factor(s) pertaining to this uncertainty for a given dimension. And the extent to which a task is "exploratory" has been considered dependent on the user and their expertise and experience [10, 15]. In this paper, we try to answer these research questions:

- What are the main dimensions and characteristics of exploratory search?
- How do people rate the different dimensions and characteristics of the exploratory search when performing a literature review?
- How does the experience of the searcher influence how exploratory the literature review search is?

To this end, we reviewed the literature on exploratory search to provide a conceptual model of exploratory search and highlight the fundamental characteristics for its dimensions (section 3). We constructed a questionnaire given these characteristics to create an instrument to capture how exploratory a task is across these dimensions (section 4). We then issued the questionnaire to participants asking about their experiences conducting literature reviews and reporting our results in section 5.

To the best of our knowledge, despite the various definitions of what an exploratory search is, there have been no previous studies aimed to measure how exploratory a search is. Thus, this is one of the first investigations exploring how the proposed definitions, dimensions, and characteristics describe exploratory search. We also provide one of the first detailed investigations into the nature of how exploratory literature review searches are –and more precisely identify which dimensions and characteristics indicate the exploratory nature of such searches. We believe this work will help understand the main characteristics of exploratory search and provide insights to the information seeking and retrieval community when designing exploratory support systems and tools.

2 BACKGROUND

Marchionini [23] has been a leading proponent of exploratory search. As shown in Figure 1, Marchionini divides search activities into three main types: lookup, learning, and investigation, where the learning and investigation activities are core to exploratory searches. Many of the previous researchers define the exploratory search by exclusion. For example, Marchionini [23] considers exploratory search as every search that is not lookup. Lookup or known-item search is the most basic search task with a clear and well-defined definition [1, 23]. Lookup searches are assumed to have precise search goals and return discrete and well-structured objects [1, 36]. The most distinctive types of lookup tasks are finding facts and answering specific questions [4]. Overall, having precise search goals with simple search paths are the main characteristics of lookup tasks [1]. However, broader lookup tasks are focused and goal-oriented but involve complex search processes with several search paths and may require thinking or understanding [1]. This type of lookup can be referred to as an interpretive task [1, 20].

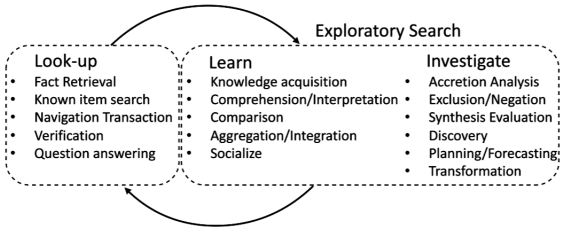

Figure 1: Search activities based on Marchionini [23].

While lookup search has a well-defined definition, exploratory search definition is still vague and considered to be complex, multifaceted, and keeps evolving [36]. White et al. [35] consider exploratory search a specialisation of information exploration where a broader class of activities is done to look for new information in a defined conceptual area. Users can employ exploratory search when they want to learn, discover, and gather information about a domain that interests them but might not have prior or specific knowledge about that domain [23, 34].

It is noticeable that most of the previous researchers follow White & Roth's [36] attempt to define the exploratory search. White & Roth use exploratory search to describe two aspects: problem context and search process. White et al. [35] describe the exploratory problem context as open-ended, persistent, and multi-faceted. They also describe the exploratory information-seeking process as opportunistic, iterative, and multi-tactical. It is apparent that the literature attempts to provide characteristics of the problem context and the search process, but they do not define or fully explain these characteristics. Based on White et al. [35], exploratory problem contexts are commonly found in scientific discovery, learning, and decision-making contexts. Meanwhile, the exploratory information-seeking processes can be used in all information-seeking manners [23, 35]. For Hassan et al. [12], exploring sessions are where users are engaged in an open-ended and multi-faceted information-seeking task to foster learning and discovery by submitting multiple queries intended to address different aspects of a topic.

After reviewing the core papers and many previous studies about exploratory search, we found that the problem context and the search process are commonly used in the literature as the main dimensions to describe the exploratory search. However, there is not adequate focus on other dimensions, such as users who engage in the exploratory search, users' information needs, and the exploratory goals. Moreover, the literature mentioned some characteristics of the problem context and the search process but did not define or fully explain them. Based on our literature analysis,

we believe that the three main dimensions that describe the exploratory search and have a significant effect on the exploratory levels are: users who engage in the exploratory search; the exploratory problem context; and the exploratory search process. The following section extensively studies these three exploratory search aspects. Additionally, it models the key characteristics that control the exploratory levels.

3 EXPLORATORY SEARCH CHARACTERISTICS

We reviewed many core papers and highly cited studies about the exploratory search, exploratory tasks, and exploratory support systems in the Information Seeking and Retrieval field. We started with Marchionini's seminal paper [23] and White & Roth's book [36] on exploratory search. We also did forward and backward chaining to find more contributions that attempted to define and characterise exploratory search and design exploratory support systems [1, 3, 12, 22, 28, 31, 32, 37]. Based on the literature analysis, we provide a conceptual model of exploratory search and highlight the fundamental characteristics and definitions of its three dimensions. We then use these characteristics to design a questionnaire instrument to check how literature searches are exploratory.

3.1 The User Dimension

A few of the previous researchers describe users who engage in the exploratory search; however, they do not consider users as one of the main dimensions of the exploratory search. Some literature suggests that the degree to which the search task is exploratory is influenced by how users are unfamiliar with the topic or domain, how uncertain they are about the goal, and how clear they are about their information need [36]. Intuitively, the more uncertain the user is regarding the topic, goal, and information need, the more exploratory the search is likely to be. The following are the key characteristics of users who engage in the exploratory search:

Unfamiliarity with the domain: Users are likely to employ exploratory search to learn about a new topic. Previous researchers [16, 23, 28, 30, 36] claim that exploratory users might be unfamiliar or new to the domain they are searching in, have little knowledge about it, have insufficient expertise, or poorly understand the problem context's domain, resulting in more exploratory behaviors. Additionally, some researchers [26, 35] suggest that exploratory users might not know the right keywords beforehand, and they might gather information and study the topic of interest immediately in the process of search.

Uncertain about the goal: White & Roth [36] propose that users who engage in exploratory search might not have a precise goal in mind when they start, and the answer of the exploratory search may not be immediately apparent. Therefore, exploratory searches are typified by uncertainty about the space they search in and the nature of the problem that motivates the search [33]. Additionally, exploratory users might seek different opinions on a topic and explore various aspects to ascertain an overview of a topic [12].

Have fuzzy information need: For Kules & Capra [22], users' information needs might be unclear, ambiguous, or imprecise as exploratory users might not know the domain that they search in well or have a general interest but not specific knowledge of that domain [34]. Therefore, users' keywords are a-priori unknown, vague, and keep evolving [25]. Moreover, the exploratory problem context may be ill-structured, and users' search goal may not be apparent [36]. Therefore, exploratory users might require additional information to clarify their goals [36].

Have dynamic information need: Based on Athukorala et al. [3], exploratory information-seeking has a dynamic nature. For some researchers [3, 35, 36], the exploratory search process starts with inadequately explained search goals; therefore, exploratory users might submit tentative queries, selectively exploring and passively gathering cues about the next steps. As a result, users' knowledge and information need constantly change throughout the iterative search process. For White & Roth [36], during the exploratory searches, users are likely to understand the problem context better; as a result, they tend to make more informed decisions about interaction or information use.

In sum, if a user is more knowledgeable about the topic, and if they have a structured task with a defined goal, then presumably they would find the search task to be less exploratory in nature because they have the sufficient expertise, prior knowledge, and the terminology to formulate the search queries. Also, since their goal is clear, the information need might not be dynamic nor fuzzy. On the other hand, it has been hypothesised by some researchers [23, 28, 36] that users employ exploratory search to discover a new domain, increase their knowledge in an area, or learn about a new topic. As a result, they might not have sufficient expertise, prior knowledge, or the terminology to formulate search queries [16, 30, 36]. Furthermore, users' information needs might be fuzzy/unclear while conducting the exploratory search process [25, 33]. Moreover, exploratory searchers might not have a specific search result in mind, and they might be unsure how to achieve their goals [27, 36]. Besides, they might require additional information from external sources to clarify those goals [36]. Consequently, their information needs might be dynamic and keep developing through the search process [2]. As exploratory searchers discover new information, they might experience uncertainty and confusion [36]. For these reasons, exploratory search is considered to be challenging [1].

3.2 The Problem Context Dimension

In terms of the problem context, five key characteristics are often mentioned when describing how exploratory the search is. For instance, if the problem context is open-ended and loosely structured, containing many sub-goals and facets, then these are associated mainly with a more exploratory search problem context.

Open-ended (persistent): For White & Roth [36], open-endedness relates to uncertainty over the information available or incomplete information on the nature of the search task. The information need, the search goal, the problem context, the search process, and the search result of exploratory search are open-ended [27, 36]. The exploratory problem context, goal, and information need do not stay the same from the start to the end of the exploratory search. Additionally, having an open-ended problem context might lead to having fuzzy and dynamic information needs. Based on Athukorala

et al. [1], since the search goal is open-ended, no single answer accomplishes users' information needs or ends the search. Since the open-ended problem is not finite, i.e., the literature keeps developing, so the search will never be complete as searchers cannot cover everything related to the task. For example, trying to learn everything about Alternative Medicine may endure forever; one cannot cover all the areas of that topic.

Multi-faceted: White & Roth [36] mention this characteristic but they do not define it. Based on Kintsch [21] as in [37], the exploratory problem context and the end result might include various aspects and different concepts. Besides, the exploratory problem context might incorporate multiple sub-tasks [37]. Therefore, exploratory users might end up searching for information related to various aspects of the domain they are looking in.

Multiple-item goal: Because the exploratory problem context might be open-ended, and multifaceted, a single target answer may not exist and the target of the search is multiple items/documents [23, 36]. The final result may be an integration of different aspects of the domain. Moreover, based on Hassan et al. [12], the information goal is likely to be satisfied with a combination of information encountered during the search using multiple queries dedicated to addressing different aspects of a topic.

Ill-structured (Ill-defined): The problem context has imprecise task requirements [20]. It also may remain undefined or in a significant flux for much of the search session [36]. Therefore, users require additional information from external sources to clarify their goals and actions [36].

General rather than specific: The problem context is general, with a vague and under-specified description [37]. Exploratory search tasks provide a low specificity about the information necessary for their search, finding the required information, and recognising the needed information [22]. The exploratory problem context might be widespread among different areas of the domain and consist of various aspects of the domain.

In sum, open-ended is one of the fundamental characteristics of the exploratory problem context [23, 33]. Users might never finish their exploratory search, but they might stop when they feel they had enough information to perform another task or do not have time to carry on the investigation [23, 28, 35]. Unlike the lookup tasks, the problem context of the exploratory search can be multi-faceted, cognitively complex, ill-structured, and has imprecise task requirements [20, 23, 24, 35, 36]. In addition, the goal of an exploratory search contains multiple items [23, 37]. Exploratory search starts with imprecise and poorly defined search goals and a general search topic task with a vague and under-specified description [3, 36, 37]. As a result, users require additional information from external sources to clarify their goals and actions [20, 36].

3.3 The Search Process Dimension

In terms of the search process, five key characteristics are often mentioned when describing how exploratory the search is. For instance, the search process is iterative, multi-tactical, and opportunistic, yet unsystematic while searching over sessions.

Iterative: The exploratory search process starts with submitting tentative queries, selectively seeking and passively obtaining leads about the following steps, and iteratively searching with evolving information needs [3, 23, 35, 36]. The search process begins with an imprecise query, and then through several successive iterations of exploring the retrieved information and reformulating queries, the scope of the information need narrows down [3].

Opportunistic: White & Roth [36] mention this characteristic but do not define it; however, it can be defined as taking a greater risk on the premise of a bigger payoff. Since users don't have complete control over what to expect and do not precisely know what they are looking for, users' search process might be less direct. Users tend to select results that might have a higher opportunity to be beneficial for them. Moreover, users do not plan their next steps in advance but rather decide their next steps at each search stage.

Unsystematic: Users who engage in the exploratory search process are unsure how to achieve their goals (either the technology or the process) [36]. While searching and browsing, users encounter new information and concepts of interest, generating additional needs and guiding the search to new directions [17]. Users' exploratory search process might follow an unpredictable non-linear path during the search [17].

Multi-tactical: White & Roth [36] mention this characteristic but do not define it. However, users might employ multiple search approaches and consult different sources throughout the exploratory search process. The exploratory search process is characteristic of the alternation and iteration of querying and browsing moods [17, 23]. Users might use other ways and systems to reach the wanted information. They also might use these systems in different ways to find more relevant information.

Long-term: Exploratory searches can take place over multiple sessions and it can be long as hours, days, or even months [36].

In sum, if a user is not knowledgeable about the topic, they would presumably find the search task to be exploratory. Thus, they might employ exploratory search processes to learn more about the domain. As hypothesised by some researchers [16, 34], exploratory users might submit some tentative queries, select and scan a few documents, passively learn the terminology, and get cues to use in the following search iteration that helps them refine their knowledge and intentions. This iterative process is called the "query–browse–refine" process [16, 36]. Moreover, users' information-seeking processes can be described as opportunistic [36]: taking a more significant risk on the premise of a bigger payoff. Besides, exploratory users tend to select results that might have a higher opportunity to be beneficial for them. Since users do not have complete control over what to expect and do not know what they are looking for exactly, their search process might be less direct, non-strategic, and unsystematic [36]. The exploratory search process is multi-tactical, and the search process is cognitively complex and might take multiple days, weeks or months [23, 35, 36].

3.4 Conceptual Model of Exploratory Search

The literature claims some dimensions and characteristics of the exploratory search, but some were mentioned without explanations; others were vaguely or partially defined. This section tried to conclude and define the characteristics of the three main dimensions and highlight how they might affect each other. Based on our literature analysis, we propose a conceptual model of the exploratory search composed of three main dimensions and fourteen characteristics, as shown in Figure 2.

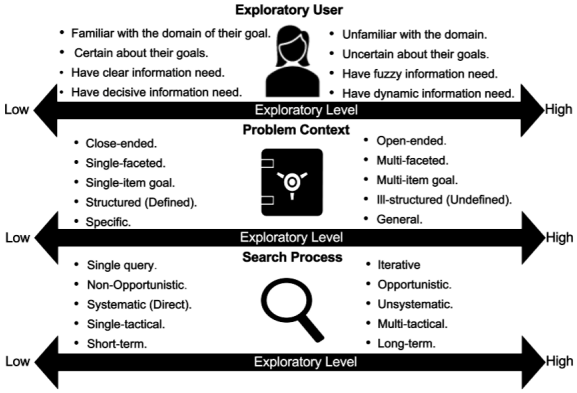

Figure 2: Our Conceptual Model of the Exploratory Search that consists of three main dimensions: the user, the problem context, and the search process –along with the different characteristics associated with each dimension.

We used these dimensions and characteristics to design a questionnaire instrument to test the provided model and collect data related to the experiences when conducting a literature review which is intuitively considered an exploratory search task by the information seeking and retrieval community [13, 19, 26, 32]. The following section has more details about the questionnaire design, data collection, and methodology.

4 RESEARCH METHODOLOGY

In the previous section, we reviewed the literature regarding the exploratory search, and we provided a conceptual model of the exploratory search. We used the model to design a web-based online questionnaire to collect data related to participants' experiences when conducting a literature review task. Our main goal is to study how academics and researchers rate the different dimensions and characteristics of the exploratory search. Additionally, what characteristics best describe the exploratory search task, and how does the searcher's experience influences the literature review search. The questionnaire was about participants' most memorable or latest literature review that they worked on for a paper, a journal, a thesis, a proposal, or an industrial report. The questionnaire contained three main parts described in more detail below.

4.1 Exploratory Search Questions

The central part of the questionnaire is the statements/questions that we formulated to elicit information regarding the characteristics of the conceptual exploratory search model, which resulted in approximately 50 statements. After piloting the questionnaire and removing similar statements, we reduced the questionnaire to 30 statements, which covered all fourteen exploratory characteristics across the three dimensions described in section 3. Table 9 in the appendix shows the full version of the 30 statements and their related exploratory dimensions and characteristics.

We asked the participants to indicate their level of agreement with these statements by choosing an option from a 5-point Likert scale (Strongly disagree; somewhat disagree; neither agree nor disagree; somewhat agree; strongly agree). In order to provide a coherent and natural flow to the questionnaire, we grouped the statements into three logical stages: 1) before starting the search, 2) during the search, and 3) after completing the search. We chose this ordering so that participants could focus their attention on recalling their experiences at each respective stage. Participants were also asked to rate the following statement by choosing an option from a 5-points Likert scale: *"Given the review you just described, please indicate your level of agreement with this statement: I would describe this review task as being an exploratory task"*. This question was asked at the end to ensure that participants' answers did not influence their previous answers.

4.2 Demographics and Search Task Questions

The questionnaire included questions related to participants' demographics, such as discipline, primary role/position, gender, and age. Also, the questionnaire had questions related to their latest or most memorable conducted literature review. Participants were asked how many times they reviewed the literature to produce a written report. Additionally, when did they perform their latest review, for what purpose (e.g., study, academic publication, funding proposal), in which topic, what type, if known, (e.g., systematic, narrative), number of references in the review, review length (i.e., number of words), and duration between the starting and completing the review task.

4.3 Ethics, Piloting, and Recruitment

We obtained ethics approval for our study from our Department's Ethics Committee (Application ID is 1579). Also, we put the questionnaire online using Qualtrics. Additionally, we piloted the questionnaire using a convenience sample to ensure all the questions were clear and fully understood by the participants. Furthermore, the pilot study's feedback helped us refine (and also reduce) the number of questions. The approximate time for participants to complete the survey was about ten minutes. To encourage the broadest possible participation from different disciplines and different work experiences, we distributed the finalised questionnaire to a whole range of channels: 1) mailing lists of staff and Ph.D. students across our university, 2) research communities and research forums on Reddit (e.g., academia, Ph.D., SampleSize), ResearchGate forums, and the national academic mailing list services (e.g., JiscMail), 3) social media platforms (e.g., Twitter, Facebook, Linkedin). The questionnaire contained an initial screening question asking whether participants had previously conducted reviews of the literature before. Since we wanted to ask participants about their search experience for such work tasks, any participant who selected zero was

directed to the end of the survey. No direct compensation was provided to participants; however, participants were invited to leave their email addresses where they would be added to a prize draw to win one of five shopping vouchers (valued at around 75 US dollars). Participants' responses related to the prize draw were stored independently in a separate questionnaire to ensure that they remained anonymous.

4.4 Participants

The questionnaire was attempted by 598 participants, of which 368 responses were fully completed. The incomplete questionnaire responses were removed from the sample. Out of the completed responses there were 222 females, 137 males, 6 Non-binary/third gender, and 3 preferred not to say their gender. Regarding the age, 59 participants were between 18 and 25 years old, 175 participants were between 26 and 35 years old, 83 participants were between 36 and 45 years old, 45 participants were above 46 years old, and 6 participants did not disclose their age. The participants came from a range of disciplines: 134 were from Engineering, Technology, and Physical Science; 67 were from Social Sciences; 45 were from Biology, Medicine, and Health; 42 were from Low, Management, Economic, and Business; 38 were from Art and Humanities, and 42 were from other disciplines. Most participants were Ph.D. Students (196), followed by Masters Students (64), then Assistant to Full Professors (35), Postdoctoral Researchers (17), Non-Academic Researchers (24), and Other (32). Most participants conducted their literature review (their most memorable or latest) for study (e.g., thesis/dissertation/proposal for Ph.D./masters/undergrad) (214), followed by academic publication (e.g., journal/conference/workshop) (120), then project report/funding proposal (26), and others (8).

5 DATA ANALYSIS AND RESULTS

After collecting 368 complete questionnaire responses, we grouped our participants based on 1) how exploratory they rated their search task, and 2) how much experience they had; so that we can explore how these two factors influenced participants' ratings of the exploratory search characteristics. Besides, to understand our data further and to find hidden patterns among the data, we did an Exploratory Factor Analysis. The following sections have more details on the analysis and the results.

5.1 Self Rated Exploratory Nature of Task

Participants rated how exploratory their review was at the end of the questionnaire. Table 1 shows the breakdown of the participant responses. We observe that about **84%** of the participants described their review of the literature that they reported on as being somewhat exploratory or very exploratory in nature. This percentage confirms previous assertions in the literature that reviewing the literature is considered an exploratory task ±[13, 19, 26]. To probe this more deeply, we consider across what dimensions/characteristics it is exploratory.

Table 1: Count of the responses on the exploratory nature of the review task shows that most participants rated it as exploratory.

Response	Count
Strongly agree	145
Somewhat agree	165
Neither agree nor disagree	32
Somewhat disagree	20
Strongly disagree	6
Total	**368**

To explore how the participants' answers of "how exploratory the task was" influenced their ratings of the exploratory search characteristics, we grouped the participants into three groups. Since we only had a small number of participants who neither agreed nor disagreed, somewhat disagreed, or strongly disagreed, we grouped these participants into one group (Not Exploratory). The final groups are as follows:

- Very Exploratory (VE): 145 participants strongly agree that conducting a literature review is an exploratory task.
- Somewhat Exploratory (SE): 165 participants somewhat agree that conducting a literature review is an exploratory task.
- Not Exploratory (NE): 58 participants strongly disagree, somewhat disagree, or neither agree nor disagree that conducting a literature review is an exploratory task.

Next, we report the average rating by each group for each dimension and characteristic –where strongly agree was considered scoring the characteristic as a 5 and strongly disagree as a 1. To determine if there were any significant differences between the groups, we used an ANOVA and then performed follow-up t-tests with Bonferroni correction ($\alpha = 0.05$) [9]. Tables' rows that are in **bold** indicate that there was a significant difference ($p < 0.05$), based on both the ANOVA and the follow-up t-tests. Also we added small annotations to these rows to point to the significantly different group(s).

5.2 User Dimension vs. Exploratory Ratings

Table 2 shows the mean for each statement related to users' characteristics given the participants ratings of how exploratory their task was: Very Exploratory (SE), Somewhat Exploratory (SE), and Not Exploratory (NE). First, we can see that those who felt their literature search was more exploratory (VE) are less likely to indicate that they were already experts on the topic before starting the search. In contrast to those who felt their literature search was not exploratory (NE), see (Q1_U) in Table 2. Also, the results show that the three groups are likely to indicate that they learned new keywords and concepts during the search. However, the VE group is significantly more likely to say they learned more keywords and concepts than those in the SE and NE groups (Q6_U). Thus,we might conclude that exploratory searches are associated with learning new concepts and keywords. Regarding finding surprising or unexpected information during the search, the three groups differed significantly. The VE group is significantly more likely to indicate that they found surprising or unexpected information, followed by the SE and the NE groups (Q7_U).

Table 2: Mean for each question related to *Users* (U) characteristics given the Exploratory Groups: VE, SE and NE.

#	Question	VE (1)	SE (2)	NE (3)
Q1_U	**I was expert on the topic.**	**2.64**$^{(3)}$	**2.94**	**3.1**
Q2_U	I knew the right keywords to use.	3.39	3.59	3.79
Q4_U	I knew what literature I wanted.	2.7	2.9	2.78
Q6_U	**I learned new keywords and concepts.**	**4.49**$^{(2,3)}$	**4.19**	**4.02**
Q7_U	**I found surprising or unexpected information.**	**4.2**$^{(2,3)}$	**3.87**$^{(3)}$	**3.34**
Q8_U	**I encountered new concepts that I investigated.**	**4.41**$^{(2,3)}$	**4.1**$^{(3)}$	**3.64**
Q10_U	I easily decided which result items were relevant.	3.43	3.55	3.34
Q14_U	The review's topic changed after reading some items.	3.28	3.2	2.81
Q25_U	I was satisfied with the search results that I obtained.	4.01	3.89	3.91

We found the same pattern regarding encountering new concepts; the VE group is more likely to express that they encountered new concepts, which they chose to investigate further, followed by the SE and NE groups (Q8_U). Therefore, we can conclude that the exploratory searchers are associated with finding surprising or unexpected information, encountering new concepts, and choosing to investigate them further.

5.3 Problem Context Dimension vs. Exploratory Ratings

Table 3: Mean for each question related to the *Problem Context* (PC) characteristics given the Exploratory Groups: VE, SE and NE.

#	Question	VE (1)	SE (2)	NE (3)
Q3_PC	I had a clear plan for finding relevant items.	3.29	3.45	3.36
Q5_PC	I knew how to divide the review task into sub-tasks.	3.08	3.19	3.07
Q12_PC	**What I thought was relevant changed over time.**	**3.83**$^{(2,3)}$	**3.48**	**3.33**
Q15_PC	I wanted very specific and detailed information.	4.13	3.96	3.83
Q23_PC	New materials on the topic are constantly being published.	4.13	4.12	3.97
Q26_PC	I retrieved most of the relevant documents.	3.82	3.58	3.47
Q27_PC	The review included literature from multiple topics.	4.21	4.02	4.07
Q29_PC	I stopped searching because I found all that I was looking for.	3.03	3.1	3.16
Q30_PC	I stopped working on the review because of a deadline or other tasks.	3.62	3.35	3.33

Based on the results in Table 3, it seems that the three groups (VE, SE, and NE) have more or less the same impression about the problem context characteristics. Among the nine statements related to the problem context, only one passed the ANOVA and the follow-up t-tests. The VE group is more likely to indicate that as they searched, what they thought was relevant changed over time more than the SE group, followed by the NE group. The results show significant differences between the VE group and the SE group on the one hand and between the VE group and the NE group on the other hand (Q12_PC).

5.4 Search Process Dimension vs. Exploratory Ratings

Based on the results in Table 4, the VE group is significantly more likely to indicate that the result items/documents they read helped them decide what to search for next than the NE group (Q16_SP). Also, the VE group is more likely to say that when reading a document, they looked up/examined items that were cited in it than the SE group (Q18_SP). Furthermore, there are significant differences between the VE and the NE groups and the SE and the NE groups regarding checking who had cited a document while reading it. The VE group is more likely to check who had cited a document while reading it, followed by the SE and NE groups (Q19_SP).

Table 4: Mean for each question related to the *Search Process* (SP) characteristics given the Exploratory Groups: VE, SE and NE.

#	Question	VE (1)	SE (2)	NE (3)
Q9_SP	I only examined items that I was sure were relevant.	3.06	3.16	2.72
Q11_SP	I reworded the search query many times.	4.07	3.91	3.93
Q13_SP	I was very thorough in checking through items.	4.06	3.85	3.71
Q16_SP	**The items I read helped me decide what to do next.**	**4.3**$^{(3)}$	**4.12**	**3.84**
Q17_SP	I knew which sources contained the needed items.	3.51	3.53	3.45
Q18_SP	**I looked up items that were cited in it.**	**4.5**$^{(2)}$	**4.28**	**4.17**
Q19_SP	**I checked to see who had cited the item I was reading.**	**3.48**$^{(3)}$	**3.55**$^{(3)}$	**2.95**
Q20_SP	Colleagues were able to suggest relevant items.	3.74	3.59	3.36
Q21_SP	I used different tools to search for items.	4.52	4.32	4.12
Q22_SP	I searched for items using different query fields.	3.99	3.88	3.79
Q24_SP	**I ran multiple searches to retrieve the wanted information.**	4.64$^{(2,3)}$	4.39	4.31
Q28_SP	**It took a long time to work out what I was looking for.**	4.23$^{(2)}$	3.9	3.9

Moreover, there are significant differences between the VE and the SE groups and the VE and the NE groups regarding running multiple searches to retrieve all the information they wanted than

the SE and NE groups (Q24_SP). Regarding the time that took them to complete the task, the VE group is significantly more likely to indicate that it took them a long time to complete the entire review than the SE group (Q28_SP). In sum, those doing a more exploratory task are more likely to work harder, examine more documents, feel their search is more dynamic, and spend more time on the task. Unlike those who are already experts in the domain, know the right keywords and concepts, and can easily decide which documents are relevant.

Overall, the user and the search process characteristics were more influenced than the problem context when grouping the participants based on how they rated the exploratory nature of the task. In general, the results suggest that the characteristics that best describe the exploratory users are unfamiliarity with the domain and having dynamic information needs. Also, the main characteristic that best describes the exploratory problem context is ill-structured. Additionally, the characteristics that best describe the search process are opportunistic, multi-tactical, and long-term.

5.5 Exploratory Dimensions vs. Experience

The questionnaire included a question about how many times the participant reviewed the literature (produced written reports). We used this question as an initial screening; we also used it to indicate the participant's experience. Our aim here is to study how users' experience in conducting previous literature reviews influences the exploratory characteristics when searching the literature. Therefore, we grouped our participants into three groups as follows:

- Not Experienced (NExper): 167 participants have conducted between 1 and 5 literature reviews.
- Somewhat Experienced (SExper): 126 participants have conducted between 6 and 20 literature reviews.
- Very Experienced (VExper): 75 participants have conducted more than 20 literature reviews.

5.6 User Dimension vs. Experience

Table 5 shows the mean values of the different questions related to users' characteristics given the experience groups (VExper, SExper, and NExper). The results show no significant differences between the three groups across most characteristics. However, there are some notable exceptions: First, the results show that the NExper group is significantly less likely to indicate that they were experts on the topic before starting the search than the SExper and VExper groups (Q1_U). Second, the NExper group is significantly less likely to reveal that they already knew the right keywords and concepts before starting the search than the SExper and the VExper groups (Q2_U). Third, the NExper group is more likely to indicate that they found surprising or unexpected information than the SExper group (Q7_U). Notably, despite their experiences, the three groups, low rated (Q4_U) *"I knew from the start what literature would go into the report"*. On the other hand, the three groups high rated (Q6_U) *"During the search, I learned new keywords and concepts related to the review's topic"*, which accords with our earlier observations, which showed that exploratory searchers are associated with learning new keywords and concepts.

Table 5: Mean for each question related to *Users* (U) characteristics given the Experience Groups: VExper, SExper and NExper.

#	Question	VExper(1)	SExper(2)	NExper(3)
Q1_U	**I was expert on the topic.**	**3.25**$^{(3)}$	**2.95**$^{(3)}$	**2.59**
Q2_U	**I knew the right keywords to use.**	**3.81**$^{(3)}$	**3.67**$^{(3)}$	**3.32**
Q4_U	I knew what literature I wanted.	2.84	2.9	2.72
Q6_U	I learned new keywords and concepts.	4.4	4.31	4.2
Q7_U	**I found surprising or unexpected information.**	**3.87**	**3.76**$^{(3)}$	**4.06**
Q8_U	I encountered new concepts that I investigated.	4.13	4.1	4.19
Q10_U	I easily decided which result items were relevant.	3.4	3.6	3.4
Q14_U	The review's topic changed after reading some items.	3.03	3.21	3.2
Q25_U	I was satisfied with the search results that I obtained.	3.95	4.0	3.89

5.7 Problem Context Dimension vs. Experience

Table 6: Mean for each question related to the *Problem Context* (PC) characteristics given the Experience Groups: VExper, SExper and NExper.

#	Question	VExper(1)	SExper(2)	NExper(3)
Q3_PC	**I had a clear plan for finding relevant items.**	**3.51**	**3.57**$^{(3)}$	**3.16**
Q5_PC	**I knew how to divide the review task into subtasks.**	**3.27**	**3.32**$^{(3)}$	**2.92**
Q12_PC	What I thought was relevant changed over time.	3.6	3.62	3.57
Q15_PC	I wanted very specific and detailed information.	4.01	4.02	3.99
Q23_PC	New materials on the topic are constantly being published.	4.11	4.13	4.07
Q26_PC	I retrieved most of the relevant documents.	3.64	3.7	3.64
Q27_PC	The review included literature from multiple topics.	4.08	4.15	4.08
Q29_PC	I stopped searching because I found all that I was looking for.	3.23	3.06	3.04
Q30_PC	I stopped working on the review because of a deadline or other tasks.	3.33	3.35	3.58

Results on Table 6 show no significant differences between the experience groups. However, there are two notable exceptions. First,

the SExper group is significantly more likely to express that they had a clear plan for finding relevant items than the NExper (Q3_PC). Second, the SExper group is substantially more likely to indicate that they knew how to divide the review task into sub-tasks more than the NExper group (Q5_PC). It could be argued that the previous experiences in conducting literature reviews improve skills of planning and organising such tasks.

5.8 Search Process Dimension vs. Experience

Based on the results in Table 7, the NExper group is less likely to indicate that the items they read helped them decide what to do next than the VExper and the SExper groups (Q16_SP). Also, the NExper group is significantly more likely to say that it took them a long time to work out what they were looking for than the VExper group (Q28_SP). It seems like the previous experience in searching for literature and the knowledge of the right keywords and concepts beforehand help save time while searching the literature.

Table 7: Mean for each question related to the *Search Process* (SP) characteristics given the Experience Groups: VExper, SExper and NExper.

#	Question	VExper(1)	SExper(2)	NExper(3)
Q9_SP	I only examined items that I was sure were relevant.	3.01	3.01	3.1
Q11_SP	I reworded the search query many times.	3.96	3.97	3.99
Q13_SP	I was very thorough in checking through items.	3.79	3.94	3.94
Q16_SP	**The items I read helped me decide what to do next.**	**4.35**$^{(3)}$	**4.09**$^{(3)}$	**4.1**
Q17_SP	I knew which sources contained the needed items.	3.55	3.57	3.44
Q18_SP	I looked up items that were cited in it.	4.48	4.43	4.24
Q19_SP	I checked to see who had cited the item I was reading.	3.45	3.52	3.35
Q20_SP	Colleagues were able to suggest relevant items.	3.57	3.5	3.72
Q21_SP	I used different tools to search for items.	4.35	4.33	4.41
Q22_SP	I searched for items using different query fields.	3.85	3.88	3.96
Q24_SP	I ran multiple searches to retrieve the wanted information.	4.55	4.48	4.45
Q28_SP	**It took a long time to work out what I was looking for.**	**3.72**$^{(3)}$	**4.0**	**4.19**

The analysis indicates that participants with high experience and low experience have more or less the same impressions about the problem context. However, participants who have more experience seem to be more organised while tackling the task; hence they expressed that they had a clear plan for finding relevant items and knew how to divide the review task into sub-tasks. Additionally, it seems like participants with previous experience and knowledge of the right keywords and concepts spend less time searching the literature to complete the review task. In summary, not experienced users are unfamiliar with the domain, have fuzzy information needs, see the problem context as ill-structured, and their search processes are opportunistic and take a long time.

5.9 Exploratory Factor Analysis

The main statements/questions provided in the questionnaire cover the fourteen characteristics of the three exploratory dimensions: The exploratory users, the problem context, and the search process. Table 9 in the appendix shows all the questions and their mapping with the exploratory dimensions and characteristics. We performed an *Exploratory Factor Analysis* (EFA) to discover the latent relationships between those statements/questions. Firstly, we ran Bartlett's test, which confirmed a correlation in the given data with ($p < 0.05$) [5]. Secondly, we ran the *Kaiser–Meyer–Olkin* (KMO) test, which showed that dimensionality reduction techniques such as factor analysis could be applied to our data with an overall proportion of variance of 0.80 [18]. Thirdly, we used the Scree test to plot the factors and their eigenvalues [6]. To confirm our choice of the number of factors, we used Horn's parallel analysis [14]. We also checked the reliability/internal consistency of the factors by calculating the Cronbach α for each [8]. The analysis suggested that there are at least four factors within our data. Table 8 shows the four factors' statements groups and their reliability/internal consistency. Based on Cronbach's α level of reliability, we conclude that the reliability/internal consistency of the four factors are reliable [11].

Table 8: Results of the EFA showing the statements group of each factor along with the reliability/internal consistency (α).

#	Factor	Statements/Questions	α
1	User Expertise	Q1_U Q2_U Q4_U, Q3_PC	0.75
2	Search/Work Task	Q2_U Q4_U Q10_U Q25_U, Q3_PC Q5_PC Q26_PC Q29_PC, Q9_SP Q17_SP	0.78
3	Search Process	Q23_PC Q27_PC, Q13_SP Q16_SP Q18_SP, Q21_SP Q22_SP Q24_SP	0.61
4	Knowledge Change	Q6_U Q7_U Q8_U Q14_U, Q12_PC, Q11_SP Q16_SP Q28_SP	0.78

1) The user expertise factor shares four statements, including being already experts before starting the search (Q1_U), knowing the right keywords and concepts to use when querying (Q2_U), knowing what literature would go into the report (Q4_U), and having a clear plan for finding relevant documents (Q3_PC). These statements relate to the presence of familiarity with the domain, certainty about the goal, and seeing the problem context as well-structured.

2) The search/work task factor shares ten statements, including knowing the right keywords and concepts to use when querying (Q2_U), knowing what literature would go into the review report (Q4_U), being able to easily decide which result items/documents

were relevant (Q10_U), being satisfied with the obtained search results (Q25_U), having a clear plan for finding relevant documents (Q3_PC), knowing how to divide the review task into various subtasks (Q5_PC), believing that they retrieved most of the relevant results/documents (Q26_PC), stopping the search because they found all the needed information (Q29_PC), examining only relevant items/documents (Q9_SP), and knowing which sources/databases contained the needed information/documents (Q17_SP). These statements relate to the presence of clear information need, certainty about the goal, well-structured and close-ended problem context, and a systematic search process.

3) The search process factor shares eight statements, including agreeing that new materials on their topic were constantly being published (Q23_PC), including literature from multiple sub-topics in the review (Q27_PC), being thorough in checking through results/documents to find relevant items (Q13_SP), the read documents helped them decide what to search for next (Q16_SP), when reading documents they employed backward chaining technique (checked to see items that were cited in it) (Q18_SP), using different tools to search for relevant results/documents (Q21_SP), searching for documents using different query fields (Q22_SP), and running multiple searches to retrieve all the information that they wanted (Q24_SP). These statements relate to the presence of multi-faceted and multiple-item goal problem context, and opportunistic, multi-tactical, and a long-time search process.

4) The knowledge gain/change factor shares eight statements, including learning new keywords and concepts related to the review's topic (Q6_U), finding surprising or unexpected information during the search (Q7_U), encountering new concepts and investigating them further (Q8_U), changing the review's topic in response to reading some of the retrieved documents (Q14_U), changing their thoughts about relevant documents (Q12_PC), rewording the search query many times while searching (Q11_SP), reading some of the retrieved documents helped them decide what to do next (Q16_SP), and taking a long time to complete the entire review (Q28_SP). These statements relate to the presence of unfamiliarity with the domain, ill-structured problem context, and iterative, dynamic, and opportunistic search process that takes a long time.

The EFA helped us characterise four factors when searching the literature (extending the typically considered three). The first factor describes the experts who already know the topic and how to complete the task. The second factor highlights the experts' experiences and how they plan to search the literature. The third factor highlights the exploratory tactics used when searching the literature. The fourth factor highlights the very exploratory experiences and the knowledge change when searching the literature.

Overall, The EFA highlights the characteristics of the main dimensions of the exploratory search that were covered before. Moreover, it points to another dimension: Knowledge gain/change. We believe that there is room to investigate what kind of support and help exploratory users need based on the knowledge they acquire while encountering new information and the path they take while exploring the information space. It might be useful to model users' knowledge while conducting the exploratory search and recommend information that completes the knowledge pieces that users have to help them draw a bigger and a complete picture of a specific topic they want to explore, learn or investigate.

6 DISCUSSION & CONCLUSION

We reviewed the exploratory search main definitions, dimensions, and characteristics. We then formulated a conceptual model of the exploratory search that included fourteen characteristics of the three main exploratory search dimensions: Users who engage in the search task, the problem context (of the search task), the search process that the user undertakes to complete the search task. We constructed a questionnaire to collect participants' search experiences when conducting literature reviews using the model. The majority of the 368 participants who completed the questionnaire described their task of reviewing the literature as being somewhat exploratory or very exploratory in nature (84%). The finding confirms previous assumptions in the literature ±[13, 19, 26] that reviewing the literature is indeed an exploratory search task. Moreover, participants see the task as exploratory regardless of their experience, discipline, education, or the type of the conducted review.

Regarding the task's self-rated exploratory nature grouping, we found that the two main characteristics that best describe the first dimension (user) are unfamiliarity with the domain and having dynamic information needs. Also, the main characteristic of the second dimension (problem context) is being ill-structured/ill-defined. Additionally, the three main characteristics of the third dimension (search process) are opportunistic, multi-tactical, and long-term. Regarding the experience grouping, several characteristics stood as most indicative of characterising exploratory search. The main characteristics of the user dimension are unfamiliarity with the domain and having fuzzy information needs. Also, we found that participants with high experience and low experience have more or less the same impressions about the problem context. However, the main characteristic of the problem context dimension is ill-structured. Additionally, the main characteristics of the search process are opportunistic and long-term. Exploratory searchers are associated with finding surprising or unexpected information and encountering new concepts (unfamiliar with the domain). Furthermore, exploratory search appears highly amorphous because the notion of relevance changes as the searcher goes through the process and requires probing the literature in many ways and over time (multi-tactical and long-term) without any explicit or pre-defined path (ill-structured).

While the past work has mainly focused on defining exploratory search with respect to its three main dimensions, the EFA confirms these three main dimensions; moreover, it reveals a fourth dimension to the exploratory search, which appears to capture the notion of Knowledge Gain/Change. This work motivates the community to focus on knowledge gain/change and consider it when designing information retrieval interfaces and systems. These systems should support the exploratory users who engage in exploratory search processes by tracking their knowledge gain/change and recommending relevant documents based on their knowledge and the goal they want to achieve.

This work advances our understanding of Exploratory Search. Our exploratory model can help researchers control the level of complexity/exploratory when designing exploratory tasks for their

studies. Also, this work suggests that more attention needs to be paid to facilitate how the search interfaces and tools can help map and curate exploratory users' knowledge gain and change during the search process. This departs from previous works on exploratory search, which have focused more on the task, the search process, and the user. While we have uncovered a fourth dimension of exploratory search, our work is not without limitations. We have only examined one particular search/work task, had participants focus on their most recent or memorable review task, and limited our questionnaire to be comprised of previously hypothesised characteristics and dimensions of the exploratory search. Consequently, further studies are needed to generalise these findings to other types of exploratory searches and to include additional questions about knowledge change/gain.

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APPENDIX

Table 9: Full version of the 30 questions of the questionnaire mapped to the associated characteristics of the exploratory model.

#	Question	Dimension	Characteristic
Q1_U	Before starting the search, I was already an expert on the topic.	User	Unfamiliarity with the domain
Q2_U	Before starting the search, I already knew the right keywords and concepts to use when querying or searching.	User	Have fuzzy information need
Q3_PC	From the start, I had a clear plan for finding relevant documents.	Problem Context	Ill-structured (Ill-defined)
Q4_U	I knew from the start what literature would go into the report.	User	Uncertain about the goal
Q5_PC	At the start, I knew how to divide the review task into various subtasks/activities.	Problem Context	Ill-structured (Ill-defined)
Q6_U	During the search, I learned new keywords and concepts related to the review's topic.	User	Unfamiliarity with the domain
Q7_U	During the search, I found information that was surprising or unexpected.	User	Unfamiliarity with the domain
Q8_U	During my search, I encountered new concepts which I chose to investigate further.	User	Have dynamic information need
Q9_SP	During the search, I only examined result items/documents that I was sure were relevant.	Search Process	Opportunistic
Q10_U	I was able to easily decide which result items/documents were relevant.	User	Have fuzzy information need
Q11_SP	I changed (reworded) the search query many times while searching for relevant results.	Search Process	Iterative
Q12_PC	As I searched, what I thought was relevant changed over time.	Problem Context	Ill-structured (Ill-defined)
Q13_SP	I was very thorough in checking through results/documents to find relevant items.	Search Process	Opportunistic
Q14_U	The review's topic changed in response to reading some of the retrieved documents.	User	Have dynamic information need
Q15_PC	When searching, I wanted very specific and detailed information relating to the topic.	Problem Context	General rather than specific
Q16_SP	The result items/documents I read helped me decide what to search for next.	Search Process	Opportunistic
Q17_SP	I knew which sources/databases exactly contained the information/documents I needed.	Search Process	Unsystematic
Q18_SP	When reading a document, I looked up/examined items that were cited in it.	Search Process	Multi-tactical
Q19_SP	When reading a document, I checked to see who had cited it.	Search Process	Multi-tactical
Q20_SP	My supervisors and colleagues were able to suggest me relevant documents.	Search Process	Multi-tactical
Q21_SP	I used different tools to search for relevant results/documents.	Search Process	Multi-tactical
Q22_SP	I searched for result items/documents using different query fields.	Search Process	Multi-tactical
Q23_PC	New materials on the topic are constantly being published.	Problem Context	Open-ended (persistent)
Q24_SP	I had to run multiple searches to retrieve all the information that I wanted.	Search Process	Long-term
Q25_U	I was satisfied with the search results that I obtained.	User	Uncertain about the goal
Q26_PC	I was able to judge that I had retrieved most of the relevant results/documents for the review.	Problem Context	Open-ended (persistent)
Q27_PC	The review report included literature from multiple topics related to the main topic.	Problem Context	Multi-faceted & Multiple-item goal
Q28_SP	It took a long time to work out (put together) what I was looking for.	Search Process	Long-term
Q29_PC	I stopped searching for documents because I found all that I was looking for.	Problem Context	Open-ended (persistent)
Q30_PC	I stopped working on the review because of a deadline or other tasks to work on.	Problem Context	Open-ended (persistent)