

# Domain knowledge, search behaviour, and search effectiveness of engineering and science students: an exploratory study

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## Abstract

**Introduction.** This study sought to answer three questions: 1) Would the level of domain knowledge significantly affect the user's search behaviour? 2) Would the level of domain knowledge significantly affect search effectiveness, and 3) What would be the relationship between search behaviour and search effectiveness?

**Method.** Participants were asked to rate their familiarity with 200 thesaurus terms to measure their level of domain knowledge. They also searched on three assigned topics using the COMPENDEX database. Data were collected through pre- and post-search questionnaires, thesaurus term rating form, computer logs, and search session printouts.

**Analysis.** Twenty-two engineering and science students' data were analysed both quantitatively and qualitatively. Quantitative analysis included both descriptive statistics and statistical testing, while the qualitative analysis was on the use of terms in queries.

**Results.** As the level of domain knowledge increases, the user tends to do more searches and to use more terms in queries. However, the search effectiveness remained the same for all participants.

**Conclusion.** The level of domain knowledge seems to have an effect on search behaviour, but not on search effectiveness, and search behaviour does not seem to be related to search effectiveness. The findings are limited by the small sample size and need to be confirmed in further studies.

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## Introduction

The enormous amount of digital information accessible today poses a great challenge to information retrieval systems to retrieve effectively the information the user needs. To design better, more effective retrieval systems, we need to understand users: what factors affect their search behaviour, search strategy, and the effectiveness of their searches? User characteristics as a contextual factor need to be investigated.

Among many user characteristics, the user's subject domain knowledge is considered an important factor that affects the user's information seeking behaviour and search performance ([Allen 1991b](#)). Subject domain knowledge is the 'knowledge that users have of the topic being searched, or of the general subject area from which that topic is drawn' ([Allen 1991b](#): 11). It can be considered as the contextual or the background information a user has about the topic.

Information retrieval system designs should take this contextual factor into consideration when personalizing the system for a user.

In this study, we investigate the effects of domain knowledge on users' search behaviour and search effectiveness. Our goal was to examine if users who were more knowledgeable in a field or about the topic to be searched would perform better in searching than the users who had less knowledge in the field. Instead of comparing the effects from different fields or domains or different contexts, we were interested in exploring how the amount, or the level of, domain knowledge in a particular field would impact the user's search. The context we chose is *heat and thermodynamics* in engineering and physics. We sought to answer three research questions:

1. Would the level of domain knowledge in this field have a significant effect on the user's search behaviour during the search process? Since domain knowledge is related to terminologies and vocabulary in a field ([Allen 1991a](#)), it is reasonable to assume that there would be a connection between the level of domain knowledge and the terms the user would select for use in the query formulation while performing the search.
2. Would the level of domain knowledge in this field have a significant impact on the effectiveness of searches or search performance? We assumed that the more knowledge a person has, the more familiar the user will be with the search question, and this familiarity would lead to two positive things during the search process: 1) the user would be more capable of formulating an effective query, and 2) the user would be more capable of identifying relevant documents. However, this remains a question, as Bhavnani ([2002](#)) asked: 'While domain-general knowledge may be important, is it sufficient for effective search?' We wanted to find out if this would be the case.
3. What would be the relationship between the search behaviour and search effectiveness? Would the search behaviour exhibited by the users with a higher level of domain knowledge lead to a more effective search? We assumed that users with different levels of domain knowledge related to a topic would demonstrate different kinds of search behaviour, and this would result in different search effectiveness.

Of the three research questions, we were particularly concerned with the search effectiveness issue, because that is the ultimate goal for system designs.

This paper reports the results from our study. We first review the related literature. We then discuss the methods we used in the study. The results are presented next, and finally we discuss the implications of the findings.

## Related research

The effect of domain knowledge on database searching has been studied from various aspects.

Borgman ([1989](#)) examined individual differences in information retrieval in terms of personal characteristics, technical aptitudes, and academic orientation and concluded that these factors were interrelated. Yee ([1993](#)) compared search strategies of graduate students in library science and education when searching in both their own domain and the other domain. For the students in education there were no differences in search behaviour when conducting searches on familiar versus unfamiliar topics. The library science students took more time to prepare off-line the search on education administration and they spent more time to evaluate the results in this unfamiliar field as opposed to the time they spent to conduct the search in their own field. The library science students used more thesaurus terms and more synonyms in the search on education. Marchionini *et al.*, ([1993](#)) compared domain experts with intermediary search experts. Their work revealed that domain experts were content-driven, focusing on the answers to the search questions and had clear expectations for the answer to be found while search experts were problem-driven, focusing on the problem statement and the query formulation. Kiestra *et al.*, ([1994](#)) conducted an experiment on identifying the impact of system and domain knowledge on search behaviour in an online catalog of twenty-nine students who performed equal numbers of searches in familiar and unfamiliar domains. The results indicated that domain knowledge had a significant effect in only one of three analyses concerning search time.

The above-mentioned studies have one thing in common: that is, they either compared the effects of domain knowledge between different fields or with search knowledge. The effects of the level of knowledge within the field were not investigated.

Several studies have been conducted to investigate the effects of the level of domain knowledge on searches. For example, Wildemuth ([2004](#)) investigated the effects of domain knowledge on the formulation of the user's search

tactics. She examined the tactics of a total of seventy-seven medical students searching a factual database in microbiology over a nine-month period and found that the search tactics changed over time as the students' domain knowledge changed. Vakkari *et al.*, (2003) conducted a longitudinal study investigating how twenty-two psychology students' growing understanding of the topic and search experience were related to their search tactics and terms while preparing a research proposal for a small study. Based on the results, the authors concluded that domain knowledge has an impact on searching assuming that users have a sufficient knowledge about the system used. Allen (1991a) found that there was a relationship between the level of domain (topic) knowledge and recall in searches in an online library catalogue. The study revealed that high-knowledge users in the subject area of Voyager 2 exploration of Neptune had a greater familiarity with the vocabulary of the topic. These studies, however, mainly concentrated on the search behaviour part, that is, the terms and patterns used. They did not investigate search effectiveness issue. The question of search effectiveness remains: would such search behaviour lead to an effective search?

Previous studies on users in the engineering research context provide little detailed information about the user's search behaviour that is specifically related to information retrieval systems during the search process. Fidel and Efthimiadis (1999) investigated the information seeking and searching behaviour of engineers at Boeing when they search for information on the Web. This study interviewed nine engineers and observed their searching during their daily work period. The results revealed some common search patterns. For instance, all participants use relevance and reliability as the most important factors when collecting task-related information from the Web; they narrow a search more frequently than they broaden it; they all choose ease of use as the most important criterion in selecting a method for searching information. Cheuk & Dervin (1999) studied information seeking and use by three groups: auditors, engineers and architects. Ten information seeking situation types, including task initiating situation, focus forming situation, idea assuming situation, idea confirming situation, etc., are identified. Compared to other groups, the results showed that engineers reported more frequently in idea rejecting situations, which are defined as the situations in which they were unable to understand conflicting and unexpected information. Most engineers believed that they spent most of their time investigating the causes of product failures, and exploring why testing results were unexpected, which seem to be related to the intention or purpose of the search. Ellis & Haugan (1997) studied the information seeking patterns of engineers and research scientists at Statoil's Research Centre, in Trondheim, Norway. The study identified similar behavioural characteristics of scientists and engineers. These characteristics are: surveying, chaining, monitoring, browsing, distinguishing, filtering, extracting, and ending. The results of these studies are too general to answer the research questions we sought to answer in our study.

We felt additional research is needed to determine the roles of domain knowledge in searching. We are particularly interested in learning how engineering and science students, including both undergraduate and postgraduate students, do searches and what are the relationships between their level of domain knowledge, their behaviour when searching, and the effectiveness of their searches.

## Research methods

In order to answer the three research questions, we needed to measure the involved variables and to compare the effects of the variables from different users. An experimental approach is thus the appropriate choice.

### Variables and measures

Three variables are involved in the study: the level of subject domain knowledge, user's search behaviour, and the effectiveness of the user's search. Subject domain knowledge serves as the independent variable, and the other two serve as the dependent variables.

#### Subject domain knowledge elicitation and representation

The subject domain, or information seeking context, chosen for this study is *heat and thermodynamics* in engineering and physics. This field was chosen because it is the common fundamental knowledge area of engineering and physics. The search topics, as will be described later in the *Instruments* subsection, are the applications of the theories in this field in the automobile industry.

In this study, we used a thesaurus to elicit and represent the users' level of domain knowledge because thesauri are

widely used as the tool for indexing and representing information in information retrieval systems and as the search-aid for users ([Paice 1991](#); [Kristensen 1993](#)). In particular, we used the Engineering Information Thesaurus, 2nd edition (1995) because it is used by the database COMPENDEX, which was the database used in this study. We used the *Heat and Thermodynamics* class in the thesaurus. We put each of about 200 terms in the *Heat and Thermodynamics* class on a five-point scale of familiarity and asked our participants to rate each term. The level of subject domain knowledge was measured as the participants' self-reported ratings of familiarity with these terms.

To make sure that what we measured is the participants' familiarity with the field, represented by the terminology, rather than the structure of the controlled vocabulary, we did not include any term relationship information in the rating instrument, and the terms were ordered alphabetically. Therefore, the participants could rate the terms without any knowledge of the controlled vocabulary.

It should be pointed out that there are many other ways to measure a person's level of domain knowledge. For example, by using a test that is standard in the field; by evaluating the person by domain expert(s) through interviews, and so on. For practical reasons, we chose to use ratings on thesaurus terms.

## **Search behaviour**

This is the information searching behaviour as defined by Wilson ([2000](#)): the micro-level of behaviour when a user interacts with a specific information retrieval system to search for relevant information. In this study, this is measured by the number of searches (queries), the number of words in a query, and the number of thesaurus terms used in query formulation.

## **Search effectiveness or performance**

We use the single value Mean Average Precision (MAP) score ([Baeza-Yates & Ribeiro-Neto 1999](#): 80) for each participant, as well as the total number of relevant documents identified by each participant as the measures of search effectiveness.

MAP is the average of precision figures obtained after each new relevant document is observed in the system's ranked result list and has been used as a major measure in the Text REtrieval Conferences (TREC) to measure the performance of different systems. This measure takes into account the number of the relevant documents retrieved and the ranking of these relevant documents in the result list. For a single topic it is the mean of the precision obtained after each relevant document is retrieved. For multiple topics, it is the mean of the average precision scores of each of the topics in the experiment. We chose to use this measure because, for an effective search, it is important that the participant should not only find relevant documents but also be able to use a query that can have the relevant documents ranked high in the result list.

## **System**

COMPENDEX, one of the most frequently used engineering databases, is used as our search system. COMPENDEX is available through the Axiom's Web-based database service ([now part of ProComm](#)), which allows users to perform simple and expert searches.

## **Participants**

Our initial experimental design intended to have twenty-eight participants in two groups: fourteen undergraduate students and fourteen postgraduate students, representing less knowledgeable users and knowledgeable users, respectively. The total number of twenty-eight was targeted partly because of the limited funds available for the research (a larger number could not be afforded) and partly for a practical reason: the engineering class from which we recruited the undergraduate students had only fourteen students. For balance, fourteen postgraduate students were to be recruited from engineering and sciences schools.

However, two of the undergraduate students could not participate for various reasons. For the graduate students, because of the time constraint (during a semester), we were able to recruit twelve. Of the twelve, three participants' search data had errors (they searched different databases and a different time period) and the data cannot be used in the analysis.

We finally had twenty-two students who participated in the study. Thirteen were undergraduates and nine were postgraduates. It is assumed that these students have different levels of domain knowledge relating to the subject field of this study. Each participant was paid \$20 after he or she completed the whole search process.

## Data collection

Data were collected through a *user questionnaire*, a *Thesaurus term rating form*, a *post-search questionnaire*, *computer logs*, and the printout of records of search sessions.

The *user questionnaire* ([Appendix 1](#)) was used to obtain demographic information from the subjects, such as, sex, degree level, search experience, etc. The *thesaurus term rating form* was used to elicit participants' knowledge of the subject domain. About 200 terms from the *Heat and Thermodynamics* section of the *EI Thesaurus* were associated with five-point scales, from 'know nothing about the term' to 'very familiar with the term itself and its relationships with other terms'. Only terms intended for use in indexing were included, i.e., those terms with the USE reference were ignored. The relationships among the terms were ignored in the rating form because we concentrated on measuring the level of domain knowledge, rather than the user's familiarity with the thesaurus itself.

The *Post-search questionnaire* ([Appendix 2](#)) was used to elicit the information about the search process, such as, how the relevance judgments were made, how the search queries were refined, and whether the participant is satisfied with the results.

The *Computer logs* were used to save the participants' search history and search results. With the intent to keep a hardcopy record, a printout of the search history for each subject was also generated, and this became a valuable source of our data.

## Search tasks

Three search questions were given to the participant. These tasks were generated by the instructor of the engineering class from which the undergraduate participants were drawn, and were used for class projects. They are purposely designed to elicit such information as subject domain, information searching, and search results evaluation. The search questions are included in [Appendix 1](#):

## Procedures

The experiment was conducted in a computer laboratory on campus. Before the participant came to the laboratory to perform searches, the participant was asked to complete the *thesaurus term rating form*. At the beginning of the experiment, the participant was asked to fill out the *user questionnaire* and then to perform searches on the three search questions. All participants used the same search questions. After each search, s/he completed the post-search evaluation questionnaire. This step continued until all the three questions were finished. The whole process took about two hours.

## Results

### Ratings of thesaurus terms

Ratings of the familiarity on the selected thesaurus terms by the participants range as low as 0.93, on a five-point scale from 0 to 4, and as high as 3.4. Based on the ratings, the participants were divided into two groups: a low-rating group, which is considered as the low-level domain knowledge group, and a high-rating group, as the high level domain knowledge group. It is reasonably assumed that those who had high ratings are more familiar with the terms and, therefore, are more knowledgeable in this field. The benchmark data for the ratings is presented in Table 1. A significant difference is found between the two groups by the paired *t*-test, with  $p < 0.000$ .

Subjects	Range of term rating	Mean term rating	No. of undergraduates	No. of postgraduates
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Low Group (n=11)	0.93-2.08	1.64	8	3
High Group (n=11)	2.13-3.4	2.75	5	6

**Table 1: Summary of thesaurus term ratings**

The average ratings are 1.64 and 2.75 from the low-level group and the high-level group respectively. Although the ratings are not high for both groups, a two-tailed, paired t-test finds that there is a significant difference between the two groups, with  $p < 0.000$ .

The subjects were also divided into two groups based on their level of education: postgraduate students and undergraduate students. However, there is no difference between these two groups in terms of the term ratings. Therefore, further comparisons are based on the high- and low-level groups.

## General results on search behaviour and search effectiveness

**Search behaviour:** Number of queries, average number of terms in queries, and average number of thesaurus terms in queries

In this study, the user search behaviour is measured by the number of searches and queries for the three search questions, the average number of terms used in queries, and the average number of *EI Thesaurus* terms used in queries. As shown in Table 2, the numbers of the three measures from the high-level group are all higher than those from the low-level group. On average, the participants in the high-level group carried out about fourteen more searches (more queries) in total than the low-level group members and they used, on average, one more word in their queries. Despite the obvious different results on these two measures between the two groups, no statistical significance was found by t-test, at the  $\alpha=0.05$  level. In terms of the number of the *EI Thesaurus* terms used in the queries, the two groups were at about the same level, with only a slightly higher number (0.34) from the high-level group. A detailed analysis on the use of terms in queries [is described later](#).

Subjects	Mean no. of queries per subject	Mean no. of terms per query	Mean no. of thesaurus terms per query
Low Group (n=11)	20.09	2.86	2.22
High Group (n=11)	34.64	4.0	2.56

**Table 2: Comparison of search behaviour of the two groups**

**Search Effectiveness:** Total number of relevant documents and mean average precision (MAP) scores

We measure search effectiveness by the total number of relevant documents identified by the user, and the MAP score for a user on the search results. The first measure focuses on the quantity of the relevant documents retrieved and the second measure focuses on the quality of the search: how the retrieved relevant documents were ranked in the system results. An effective search should have the relevant documents ranked high in the system returned list. The results are presented in Table 3.

**Table 3: Comparison of search performance**

Subjects	Mean no. of relevant documents	Mean MAP score
Low Group (n=11)	18.64	0.488
High Group (n=11)	20.55	0.59

As the data show, the subjects in the high-level group retrieved slightly more (1.91) relevant documents for the search questions, and obtained a slightly higher (0.1) MAP score. However, the differences between the two groups are not statistically significant, tested by t-test at  $\alpha=0.05$  level.

## Comparisons of the level of domain knowledge, search behaviour and search performance

The average numbers presented above demonstrate that, in general, the high-level subjects tend to do more searches and to use more words in queries. However, the number of thesaurus terms used in queries seems to be equal for both groups, and the search effectiveness is at about the same level between the two groups. The details of these general results can be further explored.

Figures 1 to 3 compare different measures of search behaviour and search effectiveness with the level of domain knowledge, represented by ratings on the thesaurus terms. These figures display the trends of search behaviour and search effectiveness along with the level of domain knowledge. In all three figures, the subjects on the horizontal axis are ordered based on their ratings of the thesaurus terms, which increase from left to right. In Figure 1, the measures from the corresponding subjects are average number of terms in a query and average number of thesaurus terms in a query, representing the user's search behaviour. In Figure 2 mean MAP scores, which represent search effectiveness, are exhibited the term ratings. The total number of relevant documents identified and the total number of queries used by each subjects are displayed in Figure 3. These two measures are separately part of the search behaviour and search performance measures. They are displayed in Figure 3, rather than in the other two figures, simply for convenience, because the data scale used by the two measures is much.

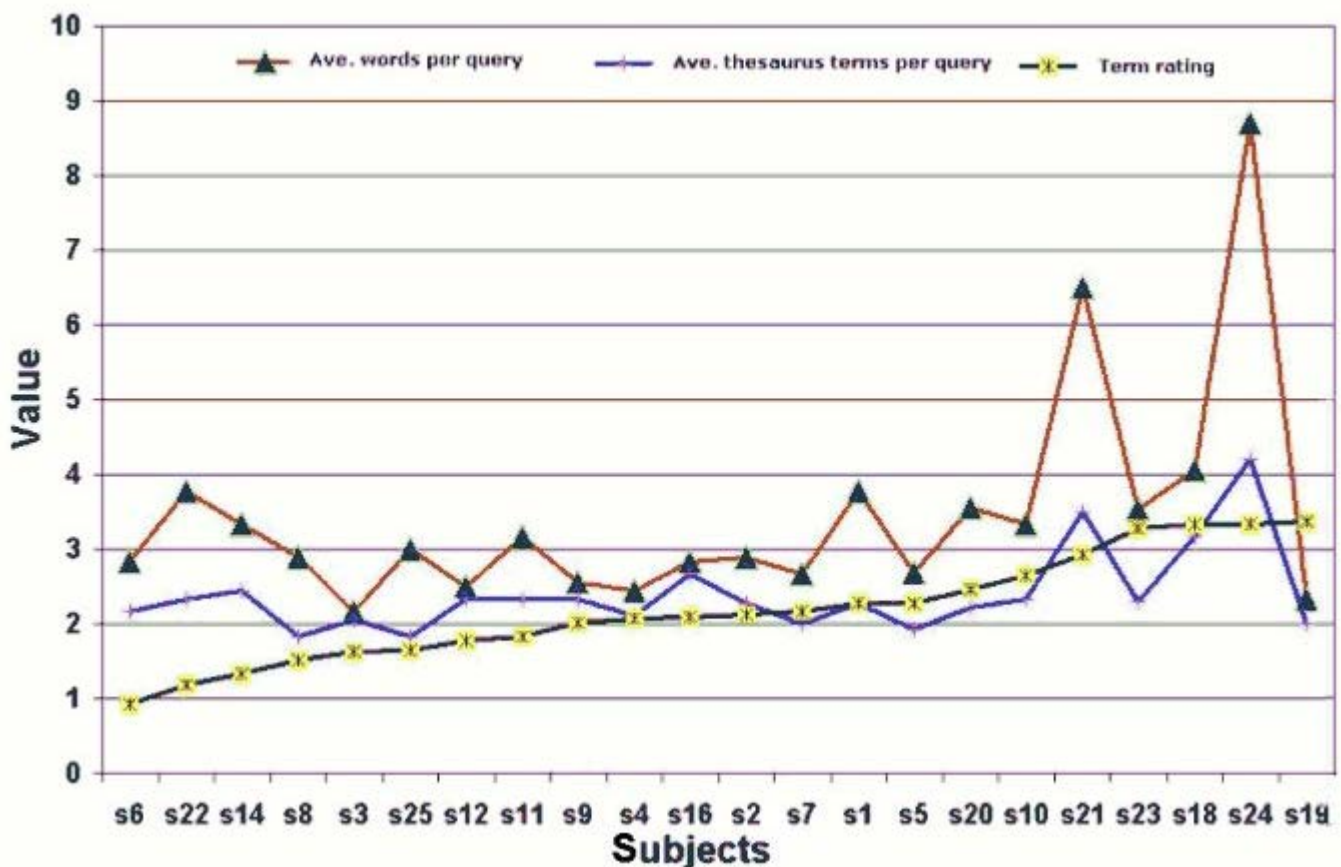


Figure 1: Subjects' scores on the three measures

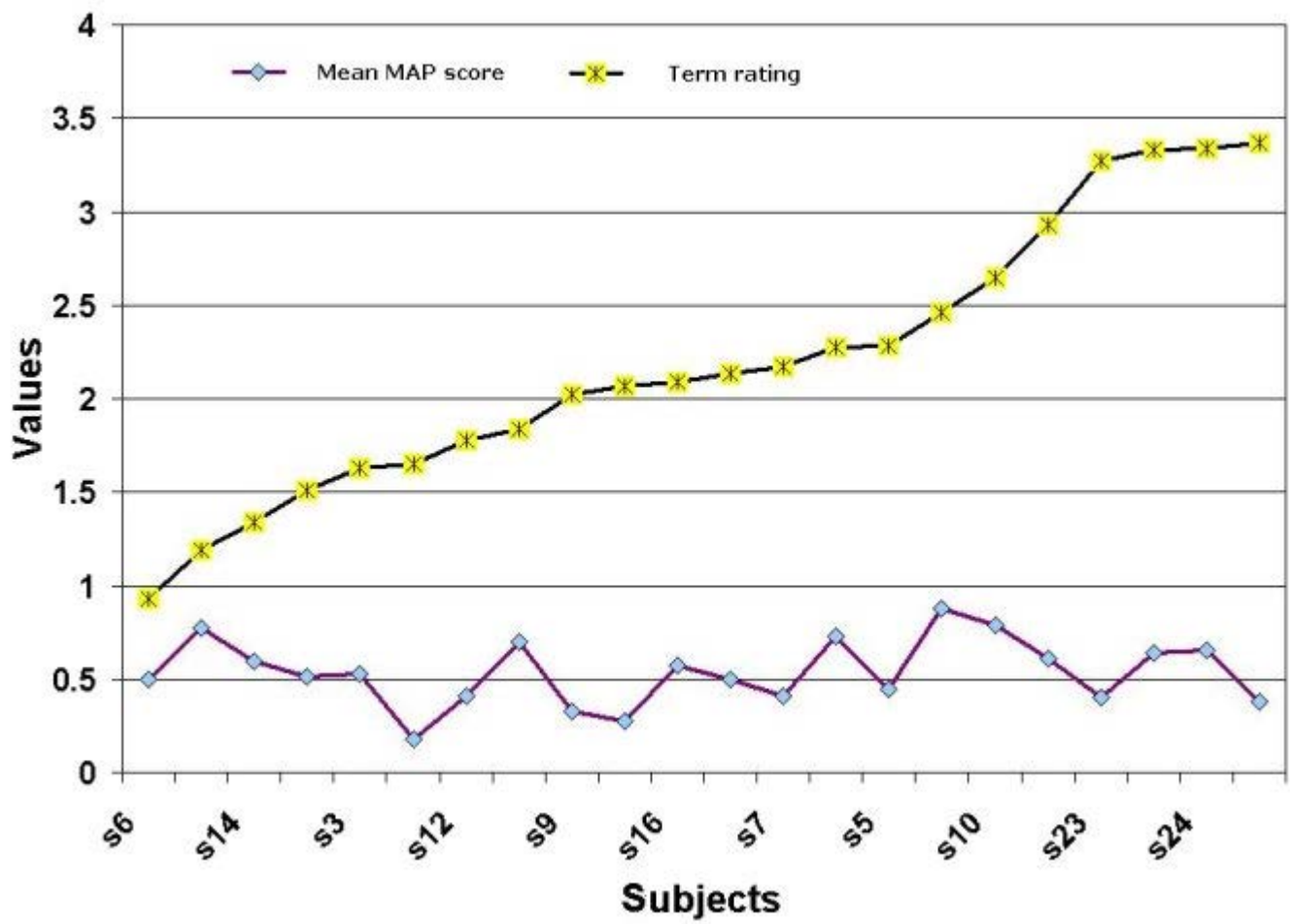
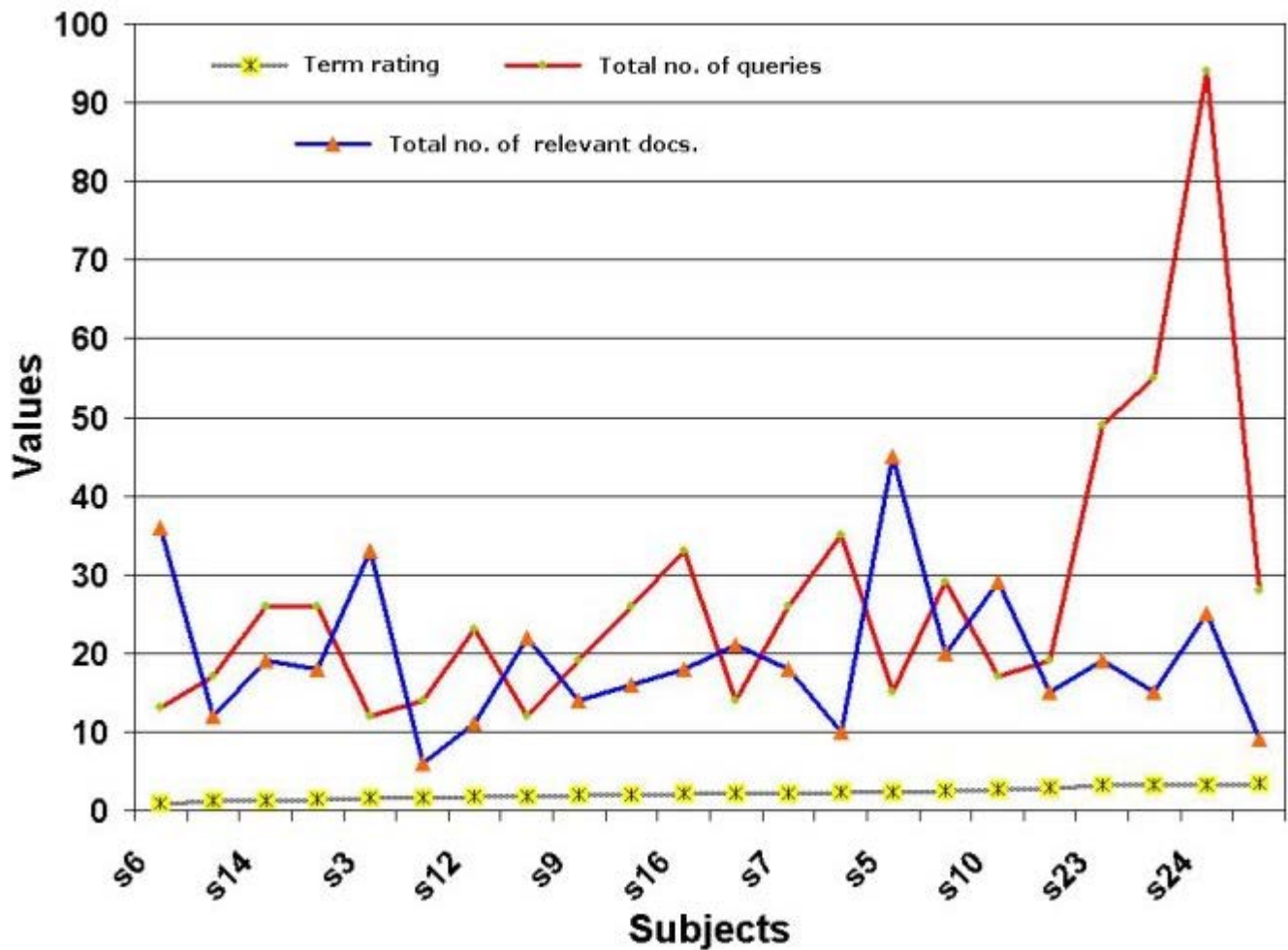


Figure 2: Comparison of term rating and MAP





**Figure 3: Comparison of term rating, no. of queries and no. of relevant documents**

The figures demonstrate more clearly the effects of the domain knowledge on search behaviour measures. As we can see from the Figures 1 and 3, as the ratings increase, the average number of terms and the number of thesaurus terms used in a query increase, so does the total number of queries in Figure 3. The figures actually reveal and explain where those differences are from between the two groups. The differences are particularly obvious between the subjects whose ratings are at the two ends. The differences are not obvious until the ratings are really high. Given the small sample size, the numbers of subjects at both ends of the rating dimension are not sufficient enough to make a statistical test. But the trends are apparent enough to make a judgment. The results here indicate that within a certain range of the level of the domain knowledge, there would be no effect. But if the difference is big enough, such as between an expert and novice in a field, the different effects would appear.

The figures also reveal that while the amount of the domain knowledge does seem to have an effect on search behaviour, it does not show any effect on the search effectiveness. In Figures 2 and 3, despite the increase in term ratings, the MAP scores in Figure 2 and the total number of relevant documents identified in Figure 3 are primarily at the same level across all subjects. These results also indicate that merely increasing the number of searches or using more terms in a query does not necessarily improve the search effectiveness.

## Use of terms in query formulation

Another way to investigate search behaviour is to examine the query terms the participants used, as studied by Wildemuth (2004), Vaakari (2003) and Allen (1991a), though the focus of our study is the effects of domain knowledge on the effectiveness of searches, rather than on search tactics or vocabulary use in searching. We compared the terms the participants used in their queries with those used in the search questions and those in the *EI Thesaurus*. Our findings are described below. It should be noted that the queries we describe here are not all of the queries the participants constructed and conducted: these are only the queries that retrieved relevant documents. Those that did not yield any relevant documents are not included.

The first search question (Q1) description was: *List three specific engineering concerns associated with automotive engine coolants. List two automotive coolant additives and describe their function.* The most frequently used search terms were *automotive*, *engine*, *coolant(s)*, and *additive(s)*. Only one subject used truncation for *cool\** in order to allow the system to retrieve more words, for example, *coolant*, *coolants*, and *cooling*. When the Axiom database loads up, the very first screen includes a section on Search Tips. The first bullet indicates *Use \* for truncation*. Only one student paid attention to this tip or s/he was familiar with truncation from previous search experience.

Filler words like *concerns* and *problem* were used four times each in the query formulation by various subjects. Even the word *review* was used to interrogate the system on the topic of automotive engine coolants. It is interesting to note that the subjects did not seem to think of synonyms when formulating their queries. The majority used the word *automotive* that came directly from the instructor's question and this is a word that the *EI Thesaurus* allows only in conjunction with *engineering* and *fuels*. Only five subjects (22.73%) used the word *automobile* in their search and nobody used both *automotive* and *automobile* connected by the *or* Boolean operator.

Of twenty-two students, only two (9.09%) subjects used the COMPENDEX built-in thesaurus in order to expand their search for Q1.

The second question (Q2) description was: *What are three of the most promising types of fuel cells? Why are they promising? What is the chemistry involved? What types are being considered for transportation?* The most frequently used terms to formulate the query were *fuel cell*, *chemistry* and *transportation*. The term *applications* was used by two subjects (9.09%) in their query formulation in conjunction with *fuel cells*. *EI Thesaurus* lists the term *Applications* without assigning a classification code for this term. The scope note describes it as a *very general term* and recommends the use of a *specific type of application* (e.g., Aerospace applications, High temperature applications, Industrial applications, etc.). ([EI Thesaurus 1995](#): 35).

It seems that the subjects were not able to select the key words from the instructor's question and determine what is the main point of a question. Six students (27.27%) used the word *promising* in their query formulation for Q2. One student (4.54%) used *most efficient* as a synonym for *promising* and another one used *most and promising or best* and *fuel cells* as his search strategy.

Other queries were formulated in natural language as if the searcher was engaged in a live conversation. One of the query formulations was *how to design a fuel cell*. Other queries included prepositions, for example, *types of fuel cells used for transportation*. Words like *types of* or *classes of* were used ten times to interrogate the system. Three subjects (13.64%) used the *expand* feature to conduct the search for Q2, thus making their search more efficient.

The third question (Q3) description was: *What are the pollutants that automotive catalytic converters are designed to reduce? What are some of the thermal-fluid engineering issues in designing automotive catalytic converters?* The most frequently used words for query formulation for Q3 were *catalytic converter(s)* (spelled *convertors* by some), *pollutants*, *thermal fluid*, *automotive*, and *automobile*. The words *automotive* and *automobile* were never connected by *or*.

For Q3 the term *engineering* was used by four subjects (18.18%) in their query formulation in conjunction with *catalytic converter(s)*. The *EI Thesaurus* lists the term *Engineering* with the 901 classification code. The scope note presents the term as *very general* and recommends the use of a *specific type of engineering*, (e.g., Automotive engineering, Electrical engineering, High temperature engineering, etc.) ([EI Thesaurus 1995](#): 236). The subjects used the term *engineering* with the connotation of *design*. A number of eight subjects used the word *design* in conjunction with *catalytic converter(s)*. The term *design* is listed in the *EI Thesaurus*, with no classification code though. *Design* is the term used for *design optimization* and some of its related terms are *Machine design*, *Product design*, *Structural design*. ([EI Thesaurus 1995](#): 171).

Again, filler words such as *types of*, *issues*, and *considerations* were used by a few subjects. One student used truncation of all of the words s/he used in the query formulation. Another student just typed all the words that came to his or her mind *automotive catalytic converter*, *pollutants*, *catalytic converter design* in one search. Another one interpreted Q3 as *automobile exhaust pollutants blocked by using catalytic converters* and simply interrogated the system by using this query. The same subject then expanded the search by using terms accepted by the built-in thesaurus such as *catalytic converters exhaust gases*, *automobiles*, and *air pollution control*, thus enhancing the recall of findings.

In general, without distinguishing high-level domain knowledge group and low-level domain knowledge group, the participants exhibited low familiarity with Boolean operators used in online searching. Most of them just typed a string of words with no connectors, many of them separated the words by commas, and some used the + sign instead of using the Boolean operator *and*. As already mentioned, the use of truncation was very limited and so was the use of the built-in thesaurus and the *expand* feature of the COMPENDEX database. The inability to extract the key words from the instructor's questions resulted in the use of irrelevant words in the query formulation. Often use of prepositions in query formulations demonstrated some participants' limited searching experience. As for the domain-specific terminology one would expect searchers to generate synonyms while interacting with the information retrieval System. This particular group of students did not make high use of synonyms, most of them limiting their search to the words derived from the instructor's questions.

## Discussion and conclusions

This study sought to answer three research questions: 1). Would the level of domain knowledge have a significant effect on the user's search behaviour? 2). Would the level of domain knowledge have a significant effect on the effectiveness of search? and 3). What would be the relationship between the search behaviour and search effectiveness? The results of our study show that the level of domain knowledge has an effect on search behaviour: as the level of domain knowledge increases, the user tends to do more searches or queries and to use more terms in queries to search for the relevant documents, though the effects are not statistically significant. This result is generally consistent with findings from previous studies. Wildemuth (2004) found that the users' search tactics, the patterns of term use in queries, changed over time as their domain knowledge changed. Vakkari *et al.*, (2003) found that the average number of terms in query increased as the user's domain knowledge increased. Allen (1991a) found that high-knowledge users employed more search expressions than low-knowledge users. All these findings indicate that the first research question above can be positively answered.

Our results do not support a positive answer to the second research question. Although the level of domain knowledge changed, the search effectiveness remained the same for all participants. This is related to the answer to the third research question: the search behaviour does not seem to be related to the search effectiveness. Despite the difference of thesaurus term ratings and of search behaviour (More knowledgeable users tend to conduct more search sessions for the same search question and use more terms in a query in order to find relevant documents), the MAP scores and the total number of relevant documents identified are essentially at the same level across all participants. These results also indicate that merely increasing the number of searches or using more terms in a query does not necessarily improve the search effectiveness. It might be the case that the difference of the domain knowledge level between the two groups in this study is not big enough. Therefore, the effective terms or words (for example, thesaurus terms) used in the queries, as discussed earlier, are approximately the same across the two groups.

Performing more searches and trying more words in queries for the same search question reflect one way of making more effort in seeking relevant information. This extra effort, however, did not seem to result in more effective searching. It may be because there is a difference between the domain knowledge and the search knowledge, as identified by previous researchers (Yee 1993). The level of domain knowledge itself may not be important unless the user has a certain amount of searching expertise. Bhavnani (2002) found that only domain-specific search knowledge is important for effective searching. The use of terms in queries in our study revealed that our participants, as a whole, had limited familiarity with database searching in general and low familiarity with COMPENDEX, one of the major databases in their field, in particular. Due to this poor searching expertise, the extra efforts made by more knowledgeable users were not converted into more effective search queries. One of the results supports this: there is no difference between the high-level knowledge group and the low-level group in terms of the average number of thesaurus terms in queries, although the high-level group tended to use more terms in a query. Therefore, the search effectiveness, as measured by the MAP scores and the number of identified relevant documents, remained the same for all users.

Results of this study imply some future directions for information retrieval system designs. How can information retrieval systems support more knowledgeable or experienced users more effectively during their information search process? More specifically, how can information retrieval systems lead these users to more effective searches? From the point of view of information retrieval system designs, the results may imply a limitation of the current systems in supporting and rewarding the more knowledgeable users. Assuming the system could identify the level of domain knowledge from a user, how can the system be designed to adapt to this particular user, so this user's

extra effort could lead to more effective searches? Could the number of queries for the same search question be used as an indicator of the searcher's level of domain knowledge? Research is needed to answer these questions.

The small sample size and the specific engineering domain context limit the generalizability of the results of this study. Due to the small sample size, the findings reported in this paper are considered as exploratory and preliminary, and the results could also be interpreted in some other ways. More research needs to be done in order to validate or invalidate these findings, using larger samples. The findings are within a specific engineering domain context. Studies in other fields may find different results. Further research should include more domain contexts and compare the results from each domain. The interactions between domain knowledge and search knowledge should also be explored.

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## APPENDIX 1

# User questionnaire and term rating

Responses to this questionnaire are used solely for research purposes. All information gathered will be handled and used confidentially.

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## Personal Information

Subject ID: \_\_\_\_\_

Age: \_\_\_\_\_

Gender: ☐ Male ☐ Female

You are currently enrolled in:

School/College: \_\_\_\_\_

Faculty/Dept.: \_\_\_\_\_

Major: \_\_\_\_\_

Level of education you are currently working towards:

☐ Bachelors (undergraduate) ☐ Masters ☐ Doctorate ☐ Other

\_\_\_\_\_

Credit hours completed in current program: \_\_\_\_\_

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How frequently do you search/use databases?

- ☐ Almost every day ☐ Once a week ☐ Once every two weeks ☐ Once a month  
☐ Once every three months ☐ Less than once every three months  
☐ Never use ☐ Other \_\_\_\_\_

When you search for information on a computer system, *including* Internet search engines, which of the following ways do you normally use to conduct your searches?

- ☐ Type in search queries ☐ Browsing ☐ Both ☐ Other \_\_\_\_\_

If you use search queries, do you normally use advanced features that are available on many systems?

- ☐ Yes ☐ No

## Term Rating

Please use the scale below to rate your familiarity with the following terms.



### Familiarity with TERM

None	Have heard of term (before taking this test)	Somewhat familiar	Quite familiar	Very familiar
0	1	2	3	4

- |                                                    |                            |                            |                            |                            |                            |
|----------------------------------------------------|----------------------------|----------------------------|----------------------------|----------------------------|----------------------------|
| 1. <b>Activity (thermodynamics)</b>                | <input type="checkbox"/> 0 | <input type="checkbox"/> 1 | <input type="checkbox"/> 2 | <input type="checkbox"/> 3 | <input type="checkbox"/> 4 |
| 2. <b>Adiabatic engines</b>                        | <input type="checkbox"/> 0 | <input type="checkbox"/> 1 | <input type="checkbox"/> 2 | <input type="checkbox"/> 3 | <input type="checkbox"/> 4 |
| 3. <b>Aerodynamics</b>                             | <input type="checkbox"/> 0 | <input type="checkbox"/> 1 | <input type="checkbox"/> 2 | <input type="checkbox"/> 3 | <input type="checkbox"/> 4 |
| 4. <b>Air conditioning</b>                         | <input type="checkbox"/> 0 | <input type="checkbox"/> 1 | <input type="checkbox"/> 2 | <input type="checkbox"/> 3 | <input type="checkbox"/> 4 |
| 5. <b>Ammonia</b>                                  | <input type="checkbox"/> 0 | <input type="checkbox"/> 1 | <input type="checkbox"/> 2 | <input type="checkbox"/> 3 | <input type="checkbox"/> 4 |
| 6. <b>Atmospheric radiation</b>                    | <input type="checkbox"/> 0 | <input type="checkbox"/> 1 | <input type="checkbox"/> 2 | <input type="checkbox"/> 3 | <input type="checkbox"/> 4 |
| 7. <b>Atmospheric thermodynamics</b>               | <input type="checkbox"/> 0 | <input type="checkbox"/> 1 | <input type="checkbox"/> 2 | <input type="checkbox"/> 3 | <input type="checkbox"/> 4 |
| 8. <b>Bearings-Low temperature</b>                 | <input type="checkbox"/> 0 | <input type="checkbox"/> 1 | <input type="checkbox"/> 2 | <input type="checkbox"/> 3 | <input type="checkbox"/> 4 |
| 9. <b>Biomedical engineering</b>                   | <input type="checkbox"/> 0 | <input type="checkbox"/> 1 | <input type="checkbox"/> 2 | <input type="checkbox"/> 3 | <input type="checkbox"/> 4 |
| 10. <b>Biomedical engineering-<br/>Cryotherapy</b> | <input type="checkbox"/> 0 | <input type="checkbox"/> 1 | <input type="checkbox"/> 2 | <input type="checkbox"/> 3 | <input type="checkbox"/> 4 |
| 11. <b>Blowers</b>                                 | <input type="checkbox"/> 0 | <input type="checkbox"/> 1 | <input type="checkbox"/> 2 | <input type="checkbox"/> 3 | <input type="checkbox"/> 4 |
| 12. <b>Boiling liquids</b>                         | <input type="checkbox"/> 0 | <input type="checkbox"/> 1 | <input type="checkbox"/> 2 | <input type="checkbox"/> 3 | <input type="checkbox"/> 4 |
| 13. <b>Bolometers</b>                              | <input type="checkbox"/> 0 | <input type="checkbox"/> 1 | <input type="checkbox"/> 2 | <input type="checkbox"/> 3 | <input type="checkbox"/> 4 |
| 14. <b>Boundary layers</b>                         | <input type="checkbox"/> 0 | <input type="checkbox"/> 1 | <input type="checkbox"/> 2 | <input type="checkbox"/> 3 | <input type="checkbox"/> 4 |
| 15. <b>Brayton cycle</b>                           | <input type="checkbox"/> 0 | <input type="checkbox"/> 1 | <input type="checkbox"/> 2 | <input type="checkbox"/> 3 | <input type="checkbox"/> 4 |
| 16. <b>Calorific value</b>                         | <input type="checkbox"/> 0 | <input type="checkbox"/> 1 | <input type="checkbox"/> 2 | <input type="checkbox"/> 3 | <input type="checkbox"/> 4 |
| 17. <b>Capillary tubes</b>                         | <input type="checkbox"/> 0 | <input type="checkbox"/> 1 | <input type="checkbox"/> 2 | <input type="checkbox"/> 3 | <input type="checkbox"/> 4 |
| 18. <b>Carbon dioxide</b>                          | <input type="checkbox"/> 0 | <input type="checkbox"/> 1 | <input type="checkbox"/> 2 | <input type="checkbox"/> 3 | <input type="checkbox"/> 4 |
| 19. <b>Cargo handling</b>                          | <input type="checkbox"/> 0 | <input type="checkbox"/> 1 | <input type="checkbox"/> 2 | <input type="checkbox"/> 3 | <input type="checkbox"/> 4 |
| 20. <b>Carnot cycle</b>                            | <input type="checkbox"/> 0 | <input type="checkbox"/> 1 | <input type="checkbox"/> 2 | <input type="checkbox"/> 3 | <input type="checkbox"/> 4 |
| .....                                              |                            |                            |                            |                            |                            |

## APPENDIX 2

### Post-search evaluation form

Responses to this questionnaire are used solely for research purposes. All information gathered will be handled and used confidentially.

Subject ID: \_\_\_\_\_

Date: \_\_\_\_\_ Time: \_\_\_\_\_

1. Before this search session, were you aware of the existence of thesauri used by information retrieval systems that can help your search?

Yes \_\_\_\_ No \_\_\_\_

a. If yes, had you used any thesaurus in your searches before?

Yes \_\_\_\_ No \_\_\_\_

b. If yes, was the use of the thesaurus helpful for you to find other terms?

No opinion 0 \_\_\_\_ Not at all 1 \_\_\_\_ 2 \_\_\_\_ 3 \_\_\_\_ 4 \_\_\_\_ 5 \_\_\_\_ Extremely helpful

## For Search Question #1

2. What information did you use to make relevance judgments on the retrieved documents in this study? (check as many as possible)

\_\_ Title \_\_ Journal

\_\_ Author \_\_ Publication year

\_\_ Abstract \_\_ Key words

\_\_ Full text \_\_ Other (please specify): \_\_\_\_\_

3. Were you generally satisfied with the information retrieved from the system for your search question? Please circle a number below:

No opinion 0 \_\_\_\_ Not at all 1 \_\_\_\_ 2 \_\_\_\_ 3 \_\_\_\_ 4 \_\_\_\_ 5 \_\_\_\_ Extremely helpful

If not satisfied, please briefly explain why: \_\_\_\_\_

4. During your search, you changed your search terms for your queries. How did you come up with the new term(s) when you refined your queries?

Note: New term(s) are those that are different from the term(s) in the initial query.

New term #1: \_\_\_\_\_

The way you came up with it (check as many as applicable):

(1) \_\_\_\_ from my memory;

(2) \_\_\_\_ from the thesaurus;

(3) \_\_\_\_ from the relevant documents retrieved by the previous query;

(4) \_\_\_\_ Other (please explain):

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

New term #3: \_\_\_\_\_

The way you came up with it (check as many as applicable):

(1) \_\_\_\_ from my memory;

(2) \_\_\_\_ from the thesaurus;

(3) \_\_\_\_ from the relevant documents retrieved by the previous query;

New term #2: \_\_\_\_\_

The way you came up with it (check as many as applicable):

(1) \_\_\_\_ from my memory;

(2) \_\_\_\_ from the thesaurus;

(3) \_\_\_\_ from the relevant documents retrieved by the previous query;

(4) \_\_\_\_ Other (please explain):

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

New term #4: \_\_\_\_\_

The way you came up with it (check as many as applicable):

(1) \_\_\_\_ from my memory;

(2) \_\_\_\_ from the thesaurus;

(3) \_\_\_\_ from the relevant documents retrieved by the previous query;

(4) \_\_ Other (please explain):

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(4) \_\_ Other (please explain):

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**Repeated For Search Question #2, etc.**

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