Effects of Domain Knowledge on User Performance and Perception in a Knowledge Domain Visualization System

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Abstract. This study investigated how the level of a user's domain knowledge affected the user's performance and perception of a knowledge domain visualization system called CiteSpace. Sixteen graduate and sixteen undergraduate students participated in a within-subjects user-centered experiment in a US university. Each of them conducted eight searching tasks in CiteSpace. Results demonstrated that there was an impact of level of domain knowledge on users' behavior, performance and perception with CiteSpace. Statistical significance was shown that users with higher level of domain knowledge (HD group) spent significantly more time completing tasks and felt significantly more satisfied with the results than users with lower level of domain knowledge (LD group). Statistical significance was also shown that the HD group perceived the system more usable than those of the LD group. The HD group claimed that they learned more new knowledge on the topics than those of the LD group.

Keywords: Information visualization, domain knowledge, knowledge domain visualization.

1 Introduction

Knowledge Domain Visualization (KDViz) systems aim to enable users to study the dynamics of knowledge domain evolution over time by constructing the knowledge structure of a particular domain to help users identify the knowledge structure of their interest [5]. CiteSpace [3], a widely used KDViz system, was developed for analyzing and visualizing scientific literature. A basic assumption of the CiteSpace system is that co- citation clusters can represent the patterns of scientific literatures. On the basis of this assumption, the CiteSpace system should be able to (1) help users learn such patterns and find the needed information effectively; and (2) enable users of higher domain knowledge level to use it more effectively than those of lower domain knowledge level.

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Researchers have tried to test the impact of the level of domain knowledge on users' information searching process with generic information systems (c.f. [15]). They also investigated the effect of user experience on Information visualization (InfoVis) systems [8], [10]. But it is not clear how the users' level of domain knowledge affect their performance of other InfoVis systems, e.g. KDViz systems.

In this paper, we are interested in the following research questions:

RQ1: What is the impact of the users' level of domain knowledge on their performance with InfoVis systems, in particular, the KDViz systems?

RQ2: How will the user's level of domain knowledge affect the user perception of InfoVis systems? Can a KDViz system really help users learn about a knowledge domain?

2 Previous Work

2.1 Effects of Domain Knowledge on Information Searches

Allen [1] found a relationship between the level of domain (topic) knowledge and recall in searches in an online library catalogue. Zhang, Anghelescu and Yuan [16] conducted a study to investigate the effect of level of domain knowledge on search effectiveness (measured by mean average precision and the total number of relevant documents) and search behavior (measured by the number of searches, the number of words in a query, and the number of thesaurus terms used in query formulation). They discovered that a person's level of domain knowledge had an impact on the person's search behavior and search performance. Their study found that as the level of domain knowledge increases, the user tends to do more searches and to use more terms in queries. Wen, Ruthven and Borlund [13] investigated the effect of topic familiarity on the user's relevance assessment behavior of retrieved information: in particular the resources and relevance criteria used by users. The results indicate that users researching an unfamiliar topic use more generic and fewer specialized resources and employ different relevance criteria. In a large user study focusing on the effect of domain knowledge on the search trail process and value, Yuan and White [15] observed differences in how people in each of the groups blazed trails and the value of the trails they generated; experts were more efficient and generated better-quality trails. Drabenstott [6] examined nondomain expert use of an Information Gateway at the University of Michigan and found that undergraduate students (nondomain experts) not only used search techniques that were different than domain experts, but found that when they did use domain expert strategies it was largely through trial-and-error, serendipity or perseverance that nondomain experts were able to find useful information.

2.2 Information Visualization Evaluation

Research has been conducted to investigate the effect of user experience on InfoVis systems. Sebrechts and Cugini [10] designed a between-subjects experiment to compare three versions of NERVE, a result visualization tool. The authors used text, 2D and 3D versions of NERVE. Nine novices, those with no professional computer experience, and six professional subjects, those with professional experience using graphical user interfaces and/or information retrieval systems, conducted a series of retrieval tasks and results showed that user experience impacted performance with more rapid response times in the 3D condition. Koshman [8] investigated the effect of level of user experience on the usability of an information visualization system VIBE. The study found that VIBE experts solved the tasks more accurately than novice and online experts.

To our knowledge, few studies have investigated the impact of domain knowledge level on the user performance of KDViz systems, which is the focus of this paper.

3 CiteSpace System

The CiteSpace system is a well-known, actively maintained and widely used KDViz system, and it is relatively stable compared to the other KDviz systems. CiteSpace was originally created to identify intellectual turning points [3]. It constructs co-citation networks among highly cited articles and enables users to manipulate the resulting graphical network in different ways. There are eight types of nodes in the CiteSpace system (version 2.1), including citing authors, noun phrases, keywords, institutions, cited authors, references, cited journals, and countries. Correspondingly, eight visualization graphs were designed to represent the patterns of scientific literatures. Fig. 1 shows the first screen of the CiteSpace system. Users can specify the time period of the literature they want to search, choose the nodes and set up thresholds in this screen. Fig. 2 displays the resulting visualization graphs which correspond to the node type references. In the experiment, these eight graphs were presented to the subjects for them to complete corresponding tasks.

4 Methodology

4.1 Experimental Design

This was a within-subjects design with thirty-two subjects. Tasks were randomly assigned across the two groups of subjects using a Latin-Square design, which ensures that no subject was given the tasks in the same order.

4.2 Subjects

The subjects were categorized into two groups: undergraduates (the lower education level) and graduates (the higher education level). Sixteen graduate students and sixteen undergraduate students from a US university participated in the experiment. All subjects came from either the department of economics or the school of business.[1]

[1] This study was approved by the Institutional Review Board from UAlbany.

Most of them were at 20-29 year old. Nearly half of the subjects majored in economics, and the rest of them were in accounting, business admin and finance. They were recruited by posting recruitment notices to the listservs of both the department of economics and the school of business.

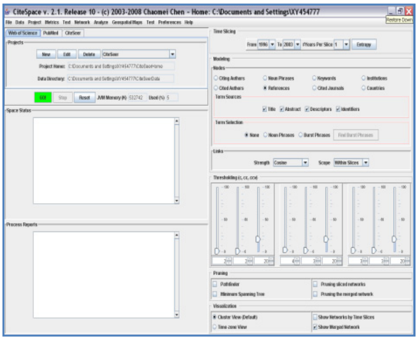

Fig. 1. The first screen of the CiteSpace system

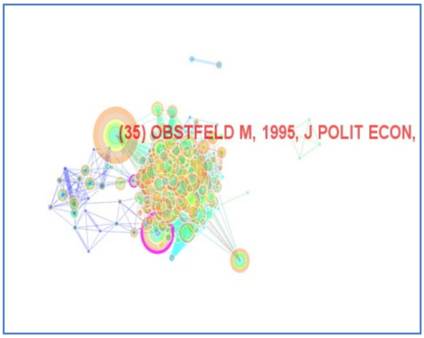

Fig. 2. Node type: References

4.3 Tasks

The domain of tasks is macroeconomics. All the tasks were related to macroeconomics. Macroeconomics was chosen because it is a general and popular topic in the field of economics. Each task type corresponded to the type of nodes specified in the CiteSpace system. In total eight types of tasks were designed.

The subjects were given eight tasks that were scenario-based topic descriptions. They followed the model of simulated work task situations proposed by Borlund [2]. Borlund found that in simulated work task situations, users' real information needs can be substituted by simulated information needs. It is our hope that these kinds of tasks can make up the shortcomings of a controlled experiment setting.

Following is an example task for the node of "cited authors."

Scenario: You want to write a term paper on macroeconomics, and you are particularly interested in investigating the development in this area during the past several years. You need to collect some papers for the literature review and have heard of a visualization system which might be able to facilitate your research.

Task: You want to identify how many times each of Moav and Hau has been cited respectively from 1998 to 2007. You also want to know which of these two has been cited more in 2007. Please type your answer in the answer sheet.

System Setup Instructions (Cited Authors): At the right side of the screen, there are several labels. In "Time Slicing," choose Year 1998-2007. In "Nodes," choose "Cited Authors." In "Thresholding," choose "2,3,15; 3,3,20; 3,3,20." Keep the default value for the rest of the items. Click Go and Visualize. When you are finished the task, close the Visualization window and click the Reset button.

4.4 Dataset

The dataset was constructed by searching topic "macroeconomics," language "English," document type "Articles," and published between the years of "1998-2007" in the ISI Web of Science[2]. It can be done by choosing settings in Fig. 1. A total of 388 records were retrieved from the Web of Science system and saved in a database, which was used in the experiment of this study.

4.5 Measures

Level of domain knowledge was defined in terms of the education level within a specific subject field/discipline. The assumption is that the higher the education level of a subject within a specific subject field/discipline, the higher the domain knowledge of the subject.

Time of task completion (in minutes) and number of mouse clicks, result satisfaction, and correctness of results were used to measure user performance. These measures have been used in earlier studies in the field [14]. Result satisfaction was measured on a seven-point scale, from 1 = "unsatisfied" to 7 = "extremely satisfied." Time was measured starting from the user opening the visualization window until the user typed the answers into the answer sheet. Result correctness was judged by the assessor, the developer of the CiteSpace system, and was measured as the assessor's rating of the saved answer(s) which answer the search topic on a 3-point scale: whether the given answer was the right answer (correct) (2), partially included the right answer (partially correct) (1) or was the wrong answer (incorrect) (0). Note that the tasks were designed with specific answer attached. Number of mouse clicks was measured by the total number of mouse clicks on nodes.

User Perception was measured in terms of ease of learning to use the system, ease of use of the system, helpfulness of the system and perceiving functionalities clearly, ease of starting a task, ease of doing the task, ease of understanding the system, and whether the subject had enough time to do the task, confidence with the results, information conveyed in the task, previous knowledge help, and effort taken to understand the tasks (all on the same type of 7-point scale, 1 = low, and 7 = high). Subjects' perception of learning new knowledge on the topic was collected when the subjects were asked whether they learned anything new about the topic. (on a 7-point scale, 1 = "None", and 7 = "A great deal." These questions were asked in the post-task questionnaire.

4.6 Procedure

The experiment was conducted in a human-computer interaction lab at a UAlbany and each subject was tested individually. Upon arrival at the lab, subjects first filled out a consent form. Then subjects conducted the following activities.

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[2] http://apps.isiknowledge.com/WOS_GeneralSearch_input.do?highlighted_tab=WOS&product=WOS&last_prod=WOS&SID=4EDBEob8bN6PPN4F1Al&search_mode=GeneralSearch#

- Filled out a questionnaire about their background, computer experience and previous searching experience.
- Next, they were given a 20-minute tutorial of the CiteSpace system. In the tutorial, the subjects were taught how to set up the time slices and choose the dataset to get the visualization graph.
- The subject was then given information about the graph (meaning of nodes, lines, co-citation, etc). In this experiment, subjects were asked to assess the visualization information in the resulting graph produced by CiteSpace based on the basic setting of time slices and the pre-defined dataset.
- Before each search, the subjects filled out a pre-task questionnaire. They performed the assigned search tasks using the CiteSpace system. They were given up to 8 minutes to conduct each search. The subjects reported their answers with the use of an answer sheet.
- After completing each search, they completed a post-task questionnaire.
- After the subjects finished all the searches using the given system, they were asked to complete an exit questionnaire.

Each subject was compensated $40 for their completion of the experiment. Morae 2.1 TechSmith logging software[3] was used to log all the interaction between each user and the system, as well as the subjects' comments (audio).

5 Results

5.1 Level of Domain Knowledge

In the pre-task questionnaire, subjects rated their topic familiarity and topic expertise in a 7-point scale, from 1="Not at all" to 7="Extremely." Graduate students were significantly more familiar (M=4.19, SD=1.62) with the topic than the undergraduate students (M=2.28, SD=1.69) from Wilcoxon signed-rank test, V=844.5, p=0.000. Graduate students had significantly more expertise (M=3.92, SD=1.56) with the topic than the undergraduate students (M=2.13, SD=1.73) from Wilcoxon signed rank test, V=1048, p=0.000. These results confirmed that graduate students in general had higher domain knowledge level than undergraduate students.

5.2 User Performance

ANOVA Results (see Table 1) showed that graduate students spent significantly more time completing tasks than undergraduates. This could be attributed to the fact that graduate students explore more visualization information (node information) than undergraduate students. This was demonstrated by data collected from Morae software. Qualitative results from the video recordings of Morae indicated that graduate students were more engaged in interacting with the visualization information (e.g. the

[3] http://www.techsmith.com/morae.html

nodes of the graph). Since they had some prior knowledge of the topics, they tended to spend time searching for the information based on their prior knowledge. One subject commented that "I am very familiar with the journal, it is a top ranked journal." When the answer was not found from the graph, they tried to search as many nodes as possible to find out an answer which was close enough to the task. This case also applied to the situation when they searched for keyword, authors and references.

Table 1. User Performance (** significant at <.01 level)

Mean (Standard deviation)	Graduates	Undergraduates	F, V, χ2, p
Time (mins)	**3.58** (2.25)**	2.72 (1.55)	F(1,254)=12.729, p=0.000
Result satisfaction(1-7)	**5.63 (1.42)****	5.15 (1.73)	V=1648.5, p=0.008
Result correctness(0-2)	1.33 (0.91)	1.56 (0.79)	χ2=4.838, df = 2, p=0.089
Number of mouse clicks	33.65 (27.41)	33.66 (22.03)	F (1,254) = 0.000, p = 0.998

Wilcoxon signed-rank test results showed that graduate students felt significantly more satisfied with the results than undergraduate students. Although undergraduate students got more correct answers than graduate students, the difference was not significant from the Pearson Chi-square test. The analysis on Morae video data indicate that undergraduate students tended to rely more on the visualization information provided by the system, while graduate students depended more on their prior knowledge on the topics. Since the CiteSpace system can only cover scientific literature collected from Web of Science, graduate students were likely to find answers which were not the best answer identified by the system itself. Both graduate students and undergraduate students had almost the same number of mouse clicks from ANOVA test.

5.3 User Perception

User perception was measured in terms of subjects' perception of using the system, doing the task, and learning new knowledge (see Measures for more details).

Table 2 displays the perception variables (collected from the post-task and exit questionnaire) and p-value of these two groups. Wilcoxon signed-rank test results of user perception of the system indicated that graduate students felt the system graphs significantly easier to understand than did undergraduate students. Graduate students thought the information was conveyed significantly better to them than the undergraduate students did. Graduate students claimed that their previous knowledge significantly helped their searching more than the undergraduate students did. Graduate students found the system significantly more helpful than undergraduate students. The system functions were significantly clearer to graduate students than to undergraduate students. For the rest of the variables, differences were not significant.

Table 2. User Perception variables (*significant at <.05 level,** significant at <.01 level)

User Perception	Graduates	Undergraduates	V,p
EasyUnd	**5.50**(1.36)**	4.75(1.84)	V=1514.5, p=0.000
InfoConvey	**5.51**(1.29)**	3.93(1.96)	V=493.5, p=0.000
PreKnowledgHelp	**3.01**(1.87)**	1.91(1.69)	V=1179, p=0.000
HelpfulSys	**5.56*(1.03)**	4.50(1.27)	V=21, p=0.044
ClearSysFunc	**5.31*(1.01)**	4.44(1.36)	V=12, p=0.017

Graduate students believed that they learned significantly more new knowledge (M=5.13, SD=1.43) than the undergraduate students did (M=3.30, SD=1.91), V=585, p=0.000. This further strengthened what we found out from the qualitative data; graduates first spent time looking for information they were quite familiar with. If the information was not found, they then looked for information that was close enough to the topic. This also explained why graduates spent significantly more time than undergraduates in searching for information. Upon discovering the expected answers, they felt happy that new knowledge was gained. This was reflected in some graduate responses such as, "this is quite interesting" and "this is interesting, quite close to what I have learned in class."

6 Discussion

The results demonstrate that the level of domain knowledge has impacts on user performance and perception of the CiteSpace system.

With respect to user performance, subjects with a higher level of domain knowledge tended to spend significantly more time on the system and were more satisfied with the results. Since this system was designed as an exploratory system, it is understandable that subjects who have higher levels of domain knowledge might like to take more time exploring the system and trying to find desirable answers. Our qualitative data supported this phenomenon. Koshman [8] found that VIBE is a system particularly effective for experienced searchers. Our results are consistent with Koshman's finding in that people with a higher level of domain knowledge found the CiteSpace system more satisfactory. Zhang, Anghelescu and Yuan [16] found that the level of domain knowledge has an impact on search behavior, but not on search effectiveness. Our results were similar to Zhang et al.'s in that we did not find significant differences on result correctness, which was measured as mean average precision in [16]. Our results indicate that the level of domain knowledge significantly affects the search performance/effectiveness in terms of task completion time and result satisfaction. However, we did not find any significant difference between the two groups in terms of accuracy and the number of mouse clicks. Graduate students spent significantly more time in completing tasks than undergraduate students which may be attributed to the fact that graduate students engaged the system more deeply and spent more time exploring the resulting graphs. This was further confirmed from the qualitative data analysis, which indicated that subjects with higher-levels of domain knowledge were more engaged in searching for information and were thus more likely to spend a greater amount of time in searching.

With respect to user perception, our results indicate that a higher level of domain knowledge helped subjects more in completing the tasks, and helped them learn more new knowledge in the searching process than those with a lower level of domain knowledge. Subjects with higher levels of domain knowledge found task completion easier than those with less domain knowledge. These results correspond well to the assumptions of CiteSpace and its design goals. As a tool for co-citation network analysis, CiteSpace encourages users to learn by revealing a vast knowledge structure of related nodes, representing authors, references, etc. Overall, the subjects thought the CiteSpace system to be helpful in finding scientific literature.

7 Conclusions

We performed a within-subjects experiment to test whether and how level of domain knowledge affects user performance and perception on InfoVis systems. We concluded that (1) the level of domain knowledge has an impact on search performance and user perception of KDViz systems; and (2) the KDViz system "CiteSpace" can help users learn about a knowledge domain, particularly for those who have some prior knowledge about the domain.

As a user-centered study, our research was constrained by the limited task type, and the limited number of subjects. Also, although the tasks were designed by following the model of Borlund's simulated work task situations, they differ from typical simulated work task situations in one key way: they include system setup instructions that explicitly tell the subject how to begin the interaction with CiteSpace. Thus, we still do not know much about how a person with high domain knowledge would freely interact with CiteSpace. In order to generalize the results to other information visualization systems and information retrieval systems, one thing we want to address in the future is how to better understand basic perceptual-cognitive tasks [4]. In the top ten unsolved information visualization problems, Chen [4] listed usability as the first problem. Particularly, he stressed that new evaluation methodologies are in urgent need. In the future, we plan to conduct more novel studies in user-centered evaluation of information visualization systems in order to contribute to discovering more new evaluation methodologies.

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