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Cognitive Model of Generic Skill: Cognitive Processes in Search and Editing

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Abstract

In the today's information society, where information access is ubiquitous and data is abundantly available, the importance of memorization is giving way to information gathering skills (search, filtering, summarization), and this focus should also be reflected in the educational process. In this study, we focus on the problem-solving skills of information searching and editing (search-editing task) and investigate a cognitive model of the problem-solving process. According to the model in this study, we examine the cognitive processes of participants solving an essay problem in an environment where they can find the required information in a document using an electronic search interface. In addition, we analyze how the participants behaved while working on the task, based on their action-log and level of achievement, and investigate the factors affecting the problem solving skills of search-editing.

Keywords: generic skills; cognitive model; problem-solving; information retrieval; text editing.

Introduction

This paper elucidates the cognitive processes required in generic skills for problem-solving by searching required information and editing the information. We model the cognitive activity of these skills.

The concept of knowledge acquisition in education is changing due to the rapid progress of information and communication technology (ICT). Digital abundance decreases the significance of simple memorization skills, while it increases that of skills to access to information effectively and to use the obtained information accurately for problem solving. These skills are sometimes referred as a part of information literacy (AASL/AECT, 1998) and as a part of key competency (Rychen & Salganik, 2003). However, the cognitive process behind actual problem solving has not yet been revealed.

Among the various kinds of complex cognitive activities, we focus on so called "search-editing activity" in this study. We analyze the cognitive processes of high school students solving an essay question in an environment where he/she can find the required information in a document using an electronic search interface (search-editing task). While the participants worked on solving the search-editing tasks, we recorded their actions in a log (action-log). We analyzed how the participants behaved while working on the task, based on their action-log and level of achievement. In the analysis, we focused on three points: 1) What did they search? 2) How did they select sentences from a document page in which they could instantly read all of it? and 3) Whether they chose the correct sentences and summarized them sufficiently to answer the question under the restrictions imposed on the task. In addition, we investigated the factors affecting the problem solving skills.

Definition of Search and Editing

We use the term "search" as the action of finding information by using the most appropriate search terms to obtain necessary and sufficient information to accomplish the goal. Inference is a validating process for search term(s), in which a person decides that the search term has to be included in a target document, but does not appear in documents unrelated to the goal. For example, the following inferences are validation of a search term: "Function words in contrast with content words appearing in all documents, so that it is not unique to the document," "A proper noun is easily used as a term to characterize the document more than a common noun."

Latent Semantic Analysis (Landauer et al., 2007) explains the appropriate choice of search terms and successful behavior to what/when/where factoid-type questions (Ferrucci et al., 2010). Unfortunately, LSA has not yet explained even the mechanism of textual entailment, which is true-false recognition of one text fragment following from another.

The similarly well-known Pirolli's Information Foraging Theory (Pirolli, 2007) explains the human behavior of the information seeking. However, the theory is not intended to focus on a way of combining the information to construct an argument.

We use the term "editing" as the action of optimizing a text in such a way as to maintain the necessary and sufficient statement towards a theme under fixed set of restrictions (the limit on the number of characters, keywords which should be included, the theme, the entailment conditions etc.).

Van Dijk and Kintsch (1983) explained the process of summarization in their situation model. In addition, Takamura and Okumura (2009) modeled the process of summarization as a maximum coverage problem, which is an optimization problem, and devised a method to automatically summarize a text. However, there seems to be no research that models a series of search and editing actions.

Cognitive Model

In Figure 1, we propose a model of cognitive processes for search-editing. In this model, we assume five types of actions to reflect three types of cognitive activities. In the phase of "goal setting," ways of collecting the information
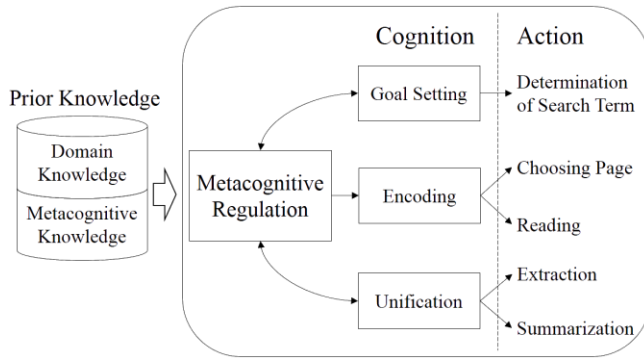
Figure 1: Cognitive model of search-editing task

required to solve a problem and the search terms to be used are determined. Next, in the "encoding phase," the searcher interprets the information that has been obtained. A page that seems to be appropriate is chosen from the search results and the information on the chosen page is read in this phase. Goal setting and encoding are cognitive processes of the search action. In the "unification" phase, the collected information is reconfigured under considerable restrictions, such as a limitation on the number of words. This would be expressed as an action of extraction of specific information from the statements read on the page and summarization of the extracted information. Unification is a cognitive process of the editing action.

These cognitive activities are supported by metacognitive regulation. Each cognitive activity is monitored to test if the activity is inappropriate to achieve the goal. If the activity is evaluated as inappropriate, it would be controlled. For example, in the encoding the goal is reset if not enough information is found to solve the problem. Similarly, in unification if the edited text is appropriate to solve the problem, re-unification of information or reset of the goal is conducted.

These cognitive activities and metacognitive regulations are thought to be affected by domain knowledge and metacognitive knowledge. Domain knowledge is knowledge of the realm concerned with the problem. Flavell (1979) divided metacognitive knowledge into three categories: knowledge of person, task and strategy. For example, those who have rich domain knowledge can easily determine correct search terms because they can comprehend the relevance of information. The search path, which prefers a proper noun rather than a common noun, can be affected by knowledge of search strategies. Not limited to how to determine search terms, prior knowledge (domain knowledge and metacognitive knowledge) affects the efficiency or accuracy of encoding and the appropriateness of weighting of information in the unification process.

Methodology of Analyzing Cognitive Process

We automatically recorded participants' action of finding information and optimizing a text with a time code to examine the cognitive process of search-editing tasks. Specifically, search terms, selected pages, and the answer text in the editing were recorded within a fixed amount of time. We regarded the actions recorded on the timeline (action-log) as explanatory variables of their cognitive activity. Based on this action-log, we can analyze how and when a participant works his cognition during the task. The protocol analysis is well-known as the method to directly access cognitive processes and to record and analyze them when participants think aloud expressing their thoughts and feelings in the process of problem-solving (Ericsson & Simon, 1993). However, in the search-editing task, it is hard for participants to think aloud the internal processes (unconscious activities) of solving a problem that lead to choosing a page. It is unlikely that the protocol reflected an actual cognitive process. Accordingly, we conducted an experiment to validate cognitive processes based on objective data, such as action-logs, but without protocols.

In previous research, the function of commercially available search engines such as Google or Yahoo! was used. These search engines include optional default functions that consider user preferences or the likelihood of a document fitting the search terms. For example, the function based on a vector space model (Salton et al., 1975) or on the Rocchio method of relevance feedback (Rocchio, 1971) optimizes the relevance between search terms and search results, and are applied in general commercial search engine. The users of these search engines can obtain satisfying search results, without their thinking to try to efficiently find appropriate query information. We discuss cognitive search processes excluding these functions because we make a biased estimation of the search skill if we provide the participants with them in the search editing task.

We provided an interface for searching information to regulate the time taken to find the page that included specified terms and to regulate the element of luck in reaching an appropriate page. We provided a document to participants, which had never been referred by the participants, to regulate their experience of reading the document, which affects the efficiency of determining a search term and page selection.

Method

Participants

The participants were 70 high school students, 36 males and 34 females. The boys were in the same class in one school, and the girls were together in the same class in another school. To enter the schools, the students had to pass the entrance examination, and the both schools are considered to be among top 7% in the prefecture. All the participants were motivated to go on to high ranking universities in Japan.

Materials

We used the expository document as the reading material, and asked the objective questions. It is known that the

evaluation of essays tend to vary widely when the subjective or controversial themes are chosen. Among many expository documents, we picked a high school history textbook. In Japan, learning materials used in school education are regulated by the government. Furthermore, the descriptive problems provided along with the learning materials have general evaluation criteria. Accordingly, the task in this experiment aimed for the participants to search information from the learning materials and edit the text based on facts.

Problems The study had two problems about Japanese history. The content of both problems was supervised by experts in Japanese history education. Both problems had to be answered within 15 minutes. The content of the problems (here translated into English) are as follows.

Problem 1 (P1).

In the regency politics of the Heian period, an important role was played not only by officials, such as the sesshō/kampaku regent, but also by women such as Fujiwara no Senshi and Fujiwara no Shōshi. Summarize the reasons for this in 100–150 characters (in English, about 50 words).

Problem 2 (P2).

During the Kamakura shogunate, estate stewards were appointed to manage and control manors and provinces. Using the three key terms "lord of the manor," "contracted estate steward," and "estate division," summarize in 150–200 characters (in English, about 70 words) the nominal purpose of establishing such estate stewards and how they subsequently changed following the Jōkyū War.

In P1, if a participant selected a certain page (correct page) from the document and extracted a certain set of consecutive sentences (correct part), he/she could completely answer the problem. In P2, if a participant selected a particular two pages, extracted certain consecutive statements from each page, and summarized the statements, he/she could complete a necessary and sufficient answer within the word count limitation. In P2, if the participant only used the exact extracted text from the correct pages as answer text, they would exceed the word count limitation.

Experts in Japanese history education formulated the evaluation criteria for each problem based on the course of study and criteria from the National Center Test for University Admissions, which is the standardized test of Japan. The criteria for P1 consisted of two items, and for P2 there were seven items. One point was awarded when a participant's answered text implied one of the criteria items. The answer texts were evaluated by experts who daily evaluate answer texts for descriptive problems. Each answer text was evaluated by two different experts. If the two experts disagreed in their judgment of criteria items in the answer texts, they came to a mutual agreement for a final judgment.

Questionnaire Participants completed a questionnaire before the experiment. The format for all items was a 5-point scale.
Perceived Japanese history competence. Six items were used to assess participants' perceived competence in Japanese history ($α = .86$).
Japanese reading interest. Four items were used to assess participants' interest in reading ($α = .63$).
Perceived reading competence. Three items were used to assess participants' perceived reading competence ($α = .67$).
Frequency of PC use. One item was used to assess participants' usage frequency of a PC.
Frequency of search. One item was used to assess the frequency of searching for information on a PC or cell phone.

Procedure

The participants were provided with an interface where they could edit answer sentences after searching the document.

The document referred to by the participants was a Japanese history textbook (Tokyo-Shoseki, 2010). The textbook was approved by the Japanese Ministry of Education and contains only historical facts without the author's opinion about the facts. In addition, it consisted of Japanese historical events and matters from the Old Stone Age to the contemporary age in about 400 pages. The article in the textbook consisted of various chapter units (topics) about specific historical events and social backgrounds. On an average, each page contained about 180 words, and each topic was composed of about 400–500 words in English. We divided the textbook according to topic (topic page) and provided these topic pages to the participants as the search resources in the interface.

The interface had the search form and the answer form. The participants' actions in this interface while working on the task were recorded in the action-logs. The participants could copy and paste statements derived in the search form to the answer form and edit it in the answer form. We instructed participants in the usage of the interface through a demonstration prior to the task.

The partial matching retrieval method in which AND was used as a search term was available in the interface search function. At first, the list of the topic pages, which contained the search terms, was shown in the search form (topic hit list). The sets of "the topic title," "the beginning part (about 50 words) of topic" and "the hyperlink to the topic page" were displayed as the topic hit list in the order that the topics appeared in the textbook. For example, if participants entered the search term "politics" in the search term form, topic pages that contained the character string "politics" would be shown in the topic hit list. When AND was used to search with the words "politics woman," topic pages containing both "politics" and "woman" would be displayed in no particular order in the topic hit list. If there was no topic page to hit, a message displayed on the search form to inform the participant. At the head of the topic page, there were hyperlinks for returning to the page, which was

Table 1: Descriptive statistics and correlation matrix

	Mean	SD	1	2	3	4	5	6	7	8	9
1. Number of search_P1	2.93	2.27									
2. Number of search_P2	3.30	1.80	.29*								
3. Number of correct pages_P2	1.43	0.53	.21	.44**							
4. Test score_P1	1.39	0.60	-.21	-.28*	.23						
5. Test score_P2	3.36	1.55	-.16	-.17	.33**	.22					
6. History competence	1.93	1.09	.09	.17	.32**	-.05	.05				
7. Reading interest	2.83	0.78	.16	.23	.18	.08	-.02	-.01			
8. Reading competence	2.67	0.87	-.03	.11	-.06	-.10	-.11	.10	.56**		
9. Frequency_PC	2.49	1.42	-.12	.00	-.14	-.04	-.22	.12	.20	.12	
10. Frequency_Search	4.47	0.90	-.04	-.09	-.14	.05	.14	-.05	.05	.02	.13

** $p < .01$, * $p < .05$

being displayed immediately before, and for checking before and after topics on the time-axis of Japanese history.

"The execution of a search with input of search terms" and "the transition of topic pages as displayed on the search form by participants" was recorded in the action-logs with the time stamp of their occurrence. Moreover, the character strings in the answer form (answer text) during editing were recorded for every second.

Results and Discussion

The Tendencies of Search and Editing

We used the numbers of search terms and correct pages participants chose as behavioral indicators about searching. We also used test scores as an indicator about editing. For search terms, we calculated one term if participants searched information using the same term. In addition, we counted AND searches as one term.

The descriptive statistics are provided in Table 1. The average number of search terms in P1 and P2 are 2.93 terms (SD = 2.27, range: 0–10) and 3.30 terms (SD = 1.80, range: 1–8), respectively. The proportion of the terms that included the information required to answer the problems was about 70% in each problem. In addition, the proportion of participants whose first log was searched was about 93%. Therefore, most participants did not answer the problems with prior knowledge, but searched information and edited information to get the right answers. Furthermore, the number of participants who did not choose the correct page was only one in P1. In P2, 31 participants chose two correct pages and 38 participants chose any one of those pages. These results suggest that almost all participants were capable of searching for the required information.

With regard to editing, the percentage of criteria participants met was about 70% in P1 (average score was 1.39, SD = 0.60) and about 48 % in P2 (average score was 3.36, SD = 1.55). Most participants found the correct pages, but they could not meet nearly half of the criteria. This indicated that participants had trouble unifying and editing

Table 2: The first action after choosing correct pages

	Problem1		Problem2	
	Frequency	Relative frequency	Frequency	Relative frequency
Extraction of appropriate sentence	35	50%	35	50%
Extraction of inappropriate sentence	11	16%	9	13%
Access other pages	5	7%	6	9%
Search by another term	5	7%	4	6%
Back to snippet	7	10%	10	14%
Editing without extraction	5	7%	3	4%
Failure to choose correct pages	1	1%	2	3%
other	1	1%	1	1%

information. We selected the first action after choosing the correct pages to examine as the feature for unifying and editing (Table 2). Table 2 indicates that only half of the participants extracted information required to answer the problems. These results imply that participants were able to determine appropriate search terms and choose correct pages, but unable to select, unify, and edit the information correctly.

However, it is assumed that participants completed the tasks through a trial and error process. For example, participants could refer to correct pages repeatedly and select appropriate information after accessing another page or searching another term. So we examined cognitive processes by conducting qualitative analysis on the action-logs as discussed in the next section.

Qualitative Analysis of Cognitive Process

Table 3 shows the action-log of a participant who searched for information and chose topic pages many times. He/she repeated the same action after 10:14 (m:s). The number of transitions of topic page was over 20 times. Since he/she

used limited search terms ("woman in Heian period" → "sesshō/kampaku regent AND woman"→"sesshō/kampaku regent"), he/she seems to have had a certain level of metacognitive knowledge about searching strategies. We speculate that a lack of encoding skill caused the repetitive search and transition of topic pages.

Table 4 shows the action-log of a participant who performed well. He/she searched information using appropriate terms and chose correct pages. Although he/she chose an incorrect page once at 0:37 (m:s), he/she decided that the page did not contain the required information and renewed his choice of topic pages. Following this, he/she selected the correct description and edited appropriately. Since he/she did not search information using another term but chose another page in the topic hit list, he/she decided his goal setting was appropriate. But he/she seemed to lack a full metacognitive skill because the number of characters in his answer exceeded the limitation.

Table 5 shows the action-log monitoring a participant who was not successful in problem solving and modified the editing process after starting the editing. He/she started to edit after displaying the correct topic page, but he/she could not answer "why did woman play an important role." He/she monitored this by himself and controlled his unification. Finally, he/she succeeded in extracting the description and appropriately editing his description for the answer to the problem, "Why did woman play an important role?"

Investigation of Factors Affecting Behavioral Indicators

We examined the relationship between individual characteristics assessed by self-reported scales and behavioral indicators. Correlation coefficients among these variables are provided in Table 1. We excluded the number of correct pages in P1, because almost all participants ($n = 69$) chose that page. The results showed that those who perceived having a higher competence in Japanese history chose more correct pages appropriately. On the other hand, perceived competence had no relation to behavioral indicators, such as test scores. This result contradicts the findings of Marsh and Graven (2006). However, the present study did not assess perceived competence in searching and editing. Therefore, we could not obtain a significant relationship between perceived competence and behavioral indicators.

Of the 70 participants, 43 took a class on Japanese history in their second year of senior high school, while 37 did not. Those who did attended two classes per a week. All of them learned the content regulated by the "Japanese government guidelines for teaching" and passed regular examinations, which were conducted six times per a year. Hence, we examined the influence of academic history on search and editing abilities. We conducted a Mann–Whitney U test and the results showed that academic history had a significant effect on the number of search terms in P2 ($z = 2.33$, $p < .05$). However, academic history had no significant effects

Table 3: The example of an action log with much a higher number of searches and page changes at P1

Time (m:s)	Action
1:04 -3:56	Search: "Query: woman in Heian period" (not hit) "Query: regency politics woman" (not hit) "Query: regency politics" (9 topic hits, including correct topic) plus 10 times. All trials had a large number of hits whether or not the correct topic was hit.
4:43	Displaying topic page: incorrect topic
5:37	Extraction of description: not implying criteria item
6:42 -10:14	Displaying topic pages: go and return to the adjacent 15 topic pages (each page was shown in 2–3 seconds)
…	…
15:00	Completion: The answer text consisted of 137 characters (about 60 words in English). No criteria item is implied.

Table 4: The example of an action log that performed exact search and extraction for P2

Time (m:s)	Action
0:25	Search: "Query: estate stewards" (17 topics hit, including first and second correct topics)
0:37	Displaying topic page: incorrect topic
1:07	Displaying topic page: first correct topic
2:18	Extraction of description: implying 2 criteria items
3:45	Search: "Query: estate stewards Jōkyū war" (2 topics hit, including second correct topic)
3:50	Displaying topic page: incorrect topic
4:24	Displaying topic page: second correct topic
5:34	Extraction of description: implying 5 criteria items
…	…
14:17	Completion: The answer text consists of 397 characters (about 160 words in English). All criteria items are implied.

Table 5: The example of an action log for a controlled unification process for P1

Time (m:s)	Action
0:38	Search: "Query: Fujiwara no Shōshi" (2 topics hit, including correct topic)
0:53	Displaying topic page: correct topic
2:16	Extraction of description: not implying criteria item
2:16 -4:17	Editing answer text
4:59	Deletion of all answer text and Extraction of description: implying 1 criteria item
4:59 -13:25	Editing answer text
13:25	Completion: The answer text consisted of 152 characters (about 60 words in English). 1 criteria item are implied.

on the number of correct pages selected or the test scores for each problem. These findings indicate that learning about Japanese history in senior high school does not contribute to search and editing abilities in the present study. In the traditional Japanese instruction style, teachers tend to transmit only a mere statement of facts about events and do not teach the reason and consequences of an event and ask essay problems in the exam. The senior high school attended by the participants had very few essay problems in regular exams. Most students tend to use superficial and rote learning when they take a close test or a multiple-choice test (Murayama, 2003). In other words, most students may not refer to causal connections such as, "What caused the event?" We speculate that most of the participants who took Japanese history classes could not acquire domain knowledge which facilitates metacognitive and cognitive activities in this instruction style. However, we only used two problems in the experiment and need to be careful about drawing conclusions.

General Discussion

In this study, we focused on the problem-solving skills of searching and editing information as generic skills and investigated a cognitive model of the problem-solving process. As a result, we confirmed the validity of the cognitive model. However, since the skills of metacognitive activity, metacognitive knowledge, and domain knowledge were not assessed directly in the present study, we did not examine the effects of these factors on search and editing. We would need to assess these factors and perform additional analyses of complex patterns in the logged data in order to examine the effects. In addition, the topics for search and editing tasks were restricted to Japanese history and the sample size was not very large. Therefore, in future studies, we would need to address other topics and broaden our population sample size and variety.

Search skills have been considered to be operational ones, and they depend mainly on the experience on information devices (Järvelin & Kekäläinen, 2000; Miura et al., 2006). However, it does not answer the following deeper question: why the search skills differ among the students equally skilled on the given information devices. In future studies, we need to examine this problem.

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