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Construction of a learning environment supporting learners' reflection: A case of information seeking on the Web

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Abstract

In this study, we design a learning environment that supports reflective activities for information seeking on the Web and evaluate its educational effects. The features of this design are: (1) to visualize the learners' search processes as described, based on a cognitive schema, (2) to support two types of reflective activities, such as "reflection-in-action" and "reflection-on-action", and (3) to facilitate reflective activities by comparing their own search processes to other learners' search processes. We have conducted an experiment to investigate the effects of our design. The experimental results confirm that: (1) the participants' search performance in the instructional group supported by our instructional design improved effectively than in the control group; (2) they changed their ideas about important activities when seeking information on the Web, and (3) they activated their search cycles more than the control group did.

Keywords: Architectures for educational technology system; Evaluation of CAL systems; Teaching/learning strategies

1. Introduction

Recently, with the growth of the World Wide Web (Web), many opportunities have emerged to use the Internet in daily life and classrooms. However, with the rapid increase of the volume of

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information, it is becoming increasingly difficult to find target information on the Internet. To break through this difficulty, most studies have investigated technologies to support searching, such as improvements of search engines and algorithms and a visualization of the Internet space. Few studies, though, aim to support cognitive abilities of users to find information. In this study, we explore a method for developing the ability of users in information seeking on the Web.

In this study, we focus on metacognitive activities in information seeking on the Web. Metacognition is generally referred to as knowledge and activities to monitor, control, and manipulate individual cognitive processes (Brown, Bransford, Ferrara, & Campione, 1983; Flavell, 1979), and as with other problem solving, metacognitive activities seem to be important for information seeking on the Web. In 1998, the Graphic, Visualization and Usability Center (GVU) conducted a survey interviewing over 10,000 Internet users, reporting that some users did not only have technological problems such as slow download speed or broken links, but also suffered problems due to their cognitive abilities. Such problems included the inability to find target information and to determine where he/she is (GVU, 1998). Particularly, the problem that prevents the user from determining where he/she is in the Web space, referred to as the "lost in space" problem, is likely to result from the lack of monitoring activities in the information seeking on the Web.

Metacognitive activities to monitor and control individual cognitive processes are fostered by various activities connected with cognitive efforts, such as self-explanation, self-regulation, and reflection. We focus on reflective activities within these metacognitive activities. Reflection is defined as a cognitive activity for monitoring, evaluating, and modifying one's thinking and process (Lin, Hmelo, Kinzer, & Secules, 1999). In this study, based on the standpoint that metacognitive activities help students learn with greater understanding, we examine effective methods for supporting reflective activities.

In the field of learning science, many researchers have investigated metacognitive activities that facilitate learners' problem solving and deep understanding (Lin & Lehman, 2001). Several studies have shown that experts or good learners practice metacognitive strategies more actively than novices or poor learners (Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Ertmer, Newby, & MacDougal, 1996).

Recently, based on those empirical findings, there have been many practical efforts, such as construction of learning support systems, to support students' reflection in the community of learning science.

The discovery and reflection notation (DARN) system developed by Schauble, Raghavan, and Glaser (1993) is a learning environment that displays learning processes to encourage students' reflection. DARN shows students the following three types of visual representation of their scientific inquiry processes. The student view displays each student's experimental pattern, the plan view exhibits his/her plans constructed at various stages of experimentation, and the expert view provides an expert's interpretation of each student's experimental results. To display students' activities from the multiple views allows them to reflect on their actions and ideas at various stages during science experimentation.

Lin and Lehman (1999) developed the Isopod simulation program that provides questions to facilitate students' reflection. Students explore how isopods' behaviors are affected by light, moisture, and temperature using a computer-supported simulation program. This program asks students to explain why and how they planned and designed isopod experiments, and collected and interpreted experimental data. Answering these questions allows the students to reflect on their own thinking while engaging in problem solving.

There are similar learning environments such as the CIRCSIM-Tutor (Hume, Michael, Rovick, & Evans, 1996) that provides students with prompts to aid their reflection triggered by their errors in a one-on-one tutoring environment, and the Thinker Tools (White & Frederiksen, 1998) that provides students with prompts to help them evaluate their work in physics experiments.

A computer-based learning environment, ASK Jasper (Bareiss & Williams, 1996) uses experts' annotations as a model to help students reflect on their own products. In this environment, the students learn mathematical problem solving and basic geometry concepts empirically in the context of designing playground equipment such as a swing. At each step in the design process, the students can refer to sample designs and read annotations made by experts. By referring to the experts' designs and annotations, the students reflect on their own designs and make plans for revisions.

Moreover, there are many practical learning environments that support learners' reflection by communication with others in social communities. For example, Computer-Supported Intentional Learning Environment (CSILE) provides a collaborative learning environment that allows students to share their learning experiences and supports community-based reflection (Scardamalia & Bereiter, 1991). CSILE is a network system that provides a communal database for students. In CSILE environments, students can enter text and graphic notes into the database on any topic their teacher has created. All students on the network can browse their notes, and write comments on each other's ideas. Using CSILE, the students discuss their questions and theories, compare difference perspectives from peers, teachers, and experts, and reflect on their individual and joint understanding of a problem.

Lin et al. (1999) proposed that there are at least two levels of reflection in learning: reflection on a product and its value and reflection on a process by which the product was created. They suggested that supports reflection on a process is more important because the process is less explicit than the product for learners. Moreover, they identified a process display as one of the scaffolds that supports reflection on the processes. A process display shows learners explicitly what they are doing to solve a task or learn a concept. This method allows learners to observe and analyze their own problem-solving processes and evaluate the effectiveness of their learning. For example, Geometry Tutor, which was designed by Anderson, Boyle, and Reiser (1985) to help students learn geometry, displays learners' geometric reasoning processes as a proof graph that consists of tree diagrams of their own solution paths between the "given" and "goal" states of problem solving. Schauble et al. (1993) also developed the DARN system, which shows students a graphical trace notation to support students' reflection on their scientific reasoning with computer-based laboratories. Although many studies have developed systems that provide students with learning processes, the educational effects of reflection on the problem-solving processes are not clear. It is also necessary to examine how we should show learners their problem-solving processes and how learners should reflect on their problem-solving processes. In this study, we design a learning environment that supports learners' reflection on problem-solving processes when seeking information on the Web and evaluate its educational effects.

First, in order to show learners their problem-solving processes, we have developed a feedback system that provides learners with their own information-seeking processes, which are described based on a cognitive schema. In problem-solving studies, a cognitive schema has been widely used to describe human problem-solving processes. We use such a cognitive schema to visualize learner's problem-solving processes and provide them with learners. We then investigate whether a cognitive schema can be applied as a cognitive tool in learning science. We will explain our system and the cognitive schema in the next chapter. Second, in order to help learners reflect on their problem-solving processes more effectively, we focus on two types of reflective activities that are referred to as "reflection-in-action" and "reflection-on-action," proposed by Schön (1987). Schön categorized reflection as "reflection-in-action" and "reflection-on-action" from the viewpoint of a context and time. The former refers to monitoring ongoing learning activities, while the latter means revisiting and monitoring critical events in one's own learning experiences after learning activities. Schön suggested that these two types of reflection are imperative factors for learning in any field with the purpose of effective learning transfer. In this study, we investigate an educational design to support these two types of reflective activities.

2. A search-process feedback system

We constructed a feedback system for search processes that supports learners' reflections on their problem-solving processes when seeking information on the Web (Saito & Miwa, 2003, 2004). This system supports learners' reflection on their own search processes by: (1) providing visual support for their search processes; (2) prompting searchers to reflect on their search processes.

In our previous study (Saito & Miwa, 2003), we conducted a psychological experiment to investigate how our system helps learners reflect on and deepen their understanding of their search processes. In the experiment, subjects were divided into the following two groups: the FD group, which was provided with feedback on their search processes by the system, and the non-FD group, which was not. We performed a protocol analysis and compared the subjects' reflective activities in the FD group with those in the non-FD group. The experimental results confirmed that (1) the system actually facilitated the learners' reflective activities by providing process visualization and prompts, and (2) the learners who reflected on their search processes more actively understood their own search processes more deeply.

2.1. A search-process describing schema

The system describes learners' information-seeking processes on the Web based on a schema for describing search processes, and allows these processes to be shown in real time. The search-process description schema was proposed to analyze searchers' processes for seeking information on the Web (Saito & Miwa, 2002). This schema was constructed based on the Problem Behavior Graph (PBG), proposed by Newell and Simon (1972), which is well known as one of the most fundamental schema for describing the subjects' problem-solving processes.

Usually, we begin the search with a search engine when we want to find something on the Web. Following that, we consider keywords and search queries to input to a search engine, and browse the results of a search or each Web-Page. In this schema, a phase in which keywords and search queries are considered is defined as a search in the Keyword space, while a phase in which information on the Web, such as the results of a search and Web pages, is searched is defined as a search in the Web space. Furthermore, the Web space is subdivided into the Result-of-Search space and the Web-Page space. Fig. 1 shows a sample description of the search-process description schema.

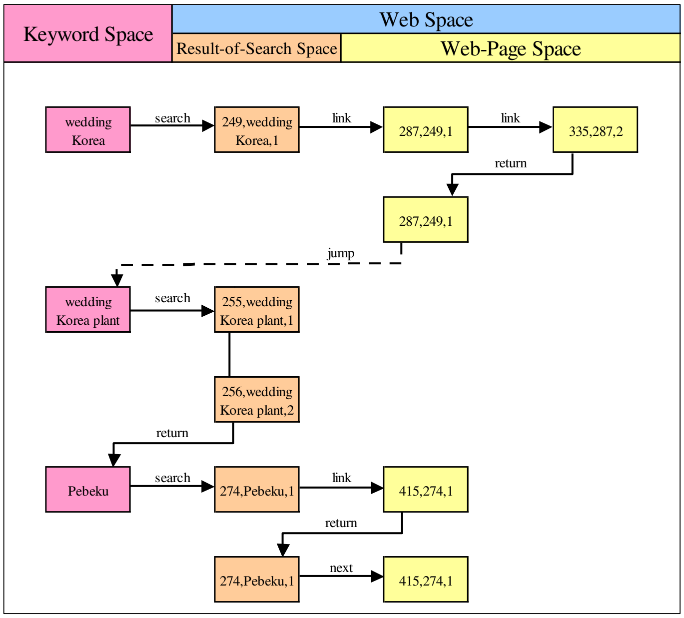


Fig. 1. Sample description of the search-process description schema.

The searchers' processes are described as transitions of nodes and operators through these three search spaces. A node represents a searcher's behavioral state, and each node's components differ from space to space. In the Keyword space, a node consists of a serial number and search queries, a node in the Result-of-Search space consists of a serial number, search queries, and the number of search results page, and a node in the Web-Page space includes a serial number and the depth of links. An operator shows an operation to the node. The following six operators are defined in this schema:

Search: searching with a search engine.
Link: going to a page connected with a link.
Next: going forward to the next page after having gone backward.
Return: going backward to the last page just visited.
Jump: revisiting a page.
Browse: browsing search results just obtained.

2.2. Prompting

The system prompts questions to help learners reflect on their own search processes presented by the system. When the system prompts a question, learners are required to answer the question while referring to the learners' own search processes. Table 1 shows each type of question presented by the system. The following three types of questions were used: (a) questions on the Keyword space; (b) on the Result-of-Search space; (c) on the Web-Page space.

Table 1
Each type of prompt presented by the system

Types of prompts	Questions
Keyword space	What kinds of keywords did you use, or how did you combine these keywords?
Result-of-Search space	How many results of search pages did you browse per search ?
Web-Page space	How many links did you click on per page ?

2.3. The system overview

A search-process feedback system was developed on Windows 2000 and written in Visual Basic 6.0. The system is composed of the WWW Browser Unit and the Search Process Drawing Unit. Fig. 2 shows a configuration of the system. In this system, learners are assumed to perform the following four activities repeatedly: (1) a learner uses the WWW Browser Unit to seek information on the WWW; (2) the Search Process Drawing Unit describes a learner's search processes and displays them on the search-process window; (3) the Search Process Drawing Unit presents a prompt; (4) a learner answers the presented question by referring to his/her own search processes described by the Search Process Drawing Unit. Through these activities, we expected that a learner monitors his/her search processes more actively, and deepens his/her understanding of information seeking activities. Next, we explain each unit of the system.

2.4. Functions of the system

2.4.1. The WWW Browser Unit

The WWW Browser Unit, like other popular browsers, i.e., Microsoft Internet Explorer and Netscape Navigator, provides functions for exploring information on the WWW while using search engines, browsing search results, and browsing various Web pages. Additionally, it records learners' actions such as the operations performed by the browser and Web-Page addresses

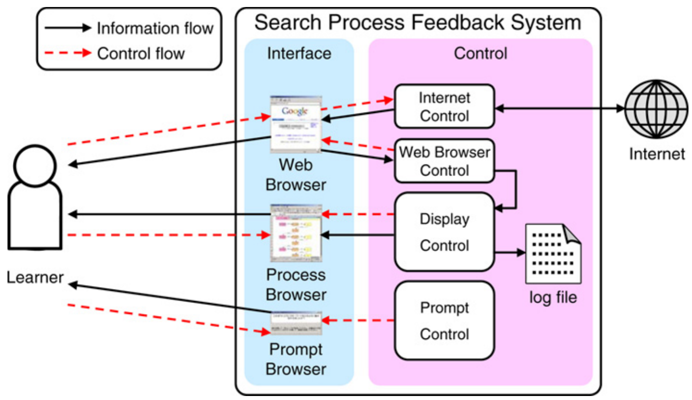
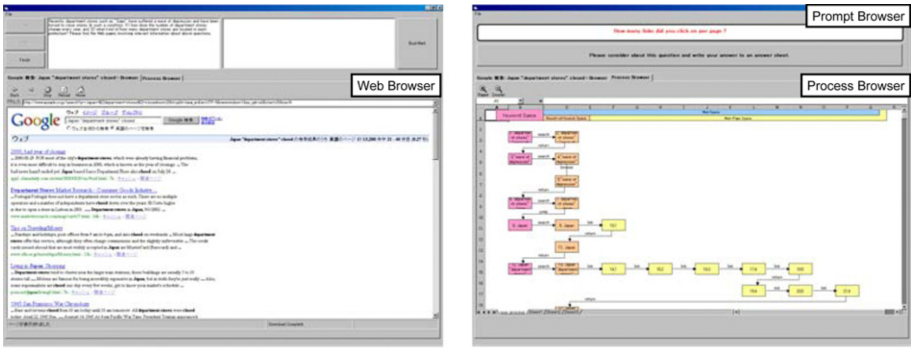


Fig. 2. The structure of the search-process feedback system.



(a) Web browser (b) Process and prompt browsers

Fig. 3. Interface of the search-process feedback system.

(URLs) browsed. Fig. 3 shows the system's interface. In Fig. 3, the left large window is the WWW Browser Unit, which is composed of an operating panel and a display window of browsed pages. The operating panel consists of buttons (back, forward, stop, reload, and home) and an address bar for entering and displaying URLs.

2.4.2. The Search Process Drawing Unit

The Search Process Drawing Unit provides the functions of drawing and displaying learners' search processes from records of their behavior. The information on learners' actions is subdivided into two categories: the operations of the browser and the URLs of Web pages browsed. This unit converts the information about the operations and the URLs to a behavior schema format while interpreting a learner's actions. In Fig. 3, the right window is the Search Process Drawing Unit. As shown in Fig. 3, a learner's search processes are drawn in Microsoft Excel. This unit also provides the function of encouraging a learner to refer to his/her own search processes. Each of the four question categories shown in Table 1 is presented at a regular interval. These questions are presented in a random order, regardless of a learner's state. The small inset window on the left-hand screen is the prompt window in which a learner answers the presented question by referring to his/her own search processes. After answering and pressing the OK button, the prompt window is closed.

3. Experiment

We have devised an instructional design that includes the search-process feedback system as a core part of the design and two types of reflection. In this section, we conducted an experiment to evaluate how support for reflection affects learners' problem-solving processes and their search performance.

3.1. Participants

Thirty-eight university freshmen participated in our experiment as part of a class on information literacy. In the class, the students learned how to use application software, such as Microsoft

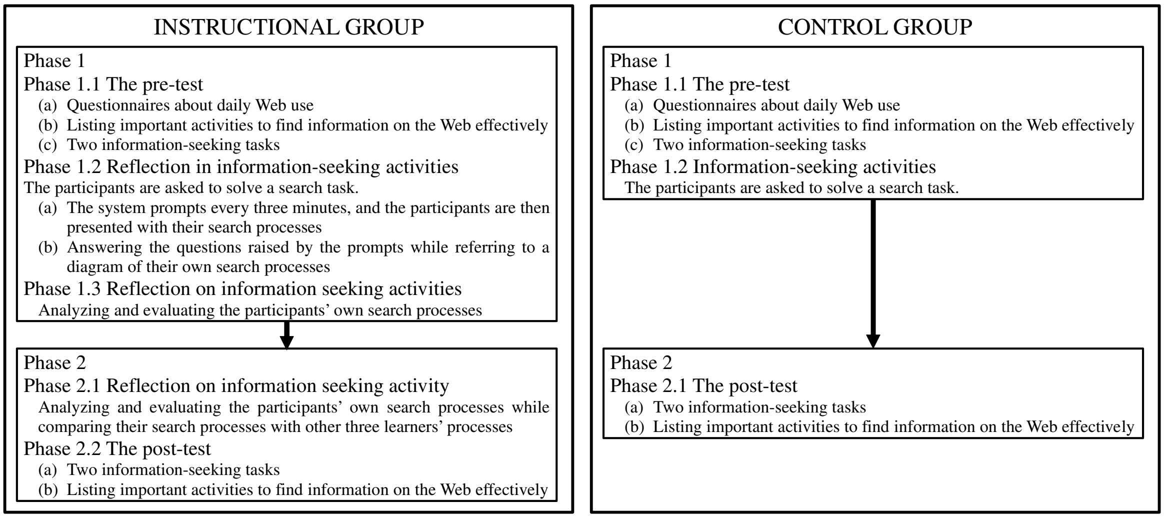


Fig. 4. Summary of the experimental procedure.

Word, Microsoft Excel, and Microsoft PowerPoint. They also learned how to search information on the Web and how to produce Web pages. Thus the skill of information retrieval is considered to be one of the most important skills needed to obtain a credit in the class. Before the experiment, the students were instructed in the basics of information retrieval on the Web via a teacher's lecture.

In the experiment, the participants were divided randomly into two groups. One group (the instructional group) was supported based on our instructional design, whereas the other (the control group) was not supported. The instructional group comprised 19 participants, as did the control group. We examined the participants' experiences of using the Web. The average time consumed per day was 26.5 min for the instructional group and 33.3 min for the control group. There was no significant difference between the two groups ($t(37) = .879$, n.s.).

The experiment consisted of two phases, which were separated by an interval of at least one day. Fig. 4 shows a summary of the experimental procedure. In the following, we explain the experimental procedures.

3.2. Pre- and post-tests

We conducted the pre- and post-tests to confirm whether the participants' search performance and their ideas about information seeking on the Web improve through their reflective activities. Each test consisted of (1) listing at least five important activities to find information on the Web effectively, and (2) solving two information-seeking tasks to measure the participants' search performance. In the information-seeking tasks, the participants were asked to find target information within 10 min for each task, using a normal Web browser, where none of the participants were provided with their search processes. The tasks were counterbalanced between the participants.

3.3. The instructional group

3.3.1. Phase 1.2 Reflection in information-seeking activities

In Phase 1.2, the participants in the instructional group experienced "reflection-in-action," wherein the participants reflect on their own search processes while seeking information on the Web. Following the pre-test, we explained to them the experimental task and how to use the system. Next, they were asked to solve a search task using the system. The search task lasted for about 20 min, and the participants in the instructional group were shown a prompt every 3 min then presented with their search processes described by the system. They considered the questions raised by the prompts while referring to a diagram of their own search processes, and entered their answers to the answer sheet.

3.3.2. Phase 1.3 Rreflection on information-seeking activities

In Phase 1.3, the participants in the instructional group experienced "reflection-on-action." After the search task, the participants reflected on their own search activities, analyzing and evaluating their own search processes for 20 min as instructed by an experimenter. First, they analyzed their search processes based on the perspective of a search among the three spaces (the Keyword space, the Result-of-Search space, and the Web-Page space) while referring to their own search processes. Second, they considered the advantages and disadvantages of their search processes and how to improve those disadvantages. Following that, they filled in their answer sheets with their ideas.

3.3.3. Phase 2.1 Reflection on information-seeking activities

In Phase 2.1, the participants in the instructional group also experienced "reflection-on-action." In contrast to Phase 1.3, the participants reflected on their search activities through comparing their own search processes with the other three learners' processes that had been selected from the control group by one of the authors.

The presented three processes are shown in Fig. 5. Process A is a process by a participant who found a correct answer. One feature of this process is that the balance of searching each space is relatively well coordinated (balanced search). Process B and Process C are processes of participants who could not find a correct answer. In contrast to Process A, these processes tend to cling to a search of one or two of the three spaces. The participant followings Process B hardly searched the Web-Page space at all. He or she repeatedly shuttled between searching in the Keyword space and the Result-of-Search space (breadth-first search).

The participant followings Process C searched the Web-Page space in great detail (depth-first search). The instructional group was provided with these three processes plus information on whether each participant found the correct answer. Then, they analyzed and evaluated their own search activities while comparing their own search processes to the three typical processes, just as in Phase 1.3.

3.4. The control group

The participants in the control group engaged in the pre- and post-tests and the search task in Phase 1.2. In Phase 1.2, the participants in the control group solved the search task without receiving the prompts and the presentation of their own search processes.

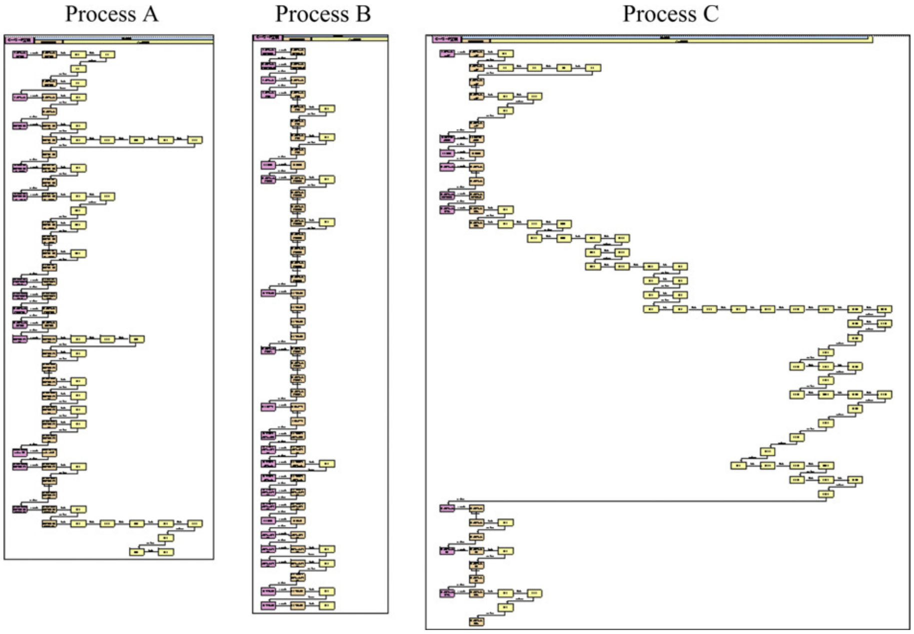


Fig. 5. The three processes presented to the participants in the instructional group.

4. Effectiveness of the instructional design

In this section, we evaluate the effects of our instructional design based on the experimental results. We compare changes from the pre- to post-tests in the instructional group with those in the control group based on the following three points: (1) the participants' search performance; (2) their ideas about important activities in information-seeking on the Web; (3) their search processes.

Three out of thirty-eight participants were eliminated because one did not understand the experimental instruction and the others did not participate in Phase 2. Therefore, we analyzed the results of the 35 participants: 17 participants from the instructional group and 18 participants from the control group.

4.1. Search performance

The scores of the search tasks in the pre- and post-tests were estimated to determine whether the participants could locate Web pages containing the target information. The participants' performances in the pre- and post-tests are shown in Table 2. Each score (0, 1, and 2) shows the number of tasks in which the participants could find a correct answer, and each frequency in each cell of this table show the number of the participants getting each score. We compared the number of participants who increased their scores from the pre-test to post-test with the number of participants who did not.

From the result of the chi-square test, Groups (the instructional/control groups) × performances (improving/not improving), we found that the number of participants who

Table 2
Participants' performances in pre- and post-tests

		Post test			
		0	1	2	Sum
(a) Instructional group					
Pre test	0	9	7	0	16
	1	1	0	0	1
	2	0	0	0	0
	Sum	10	7	0	17
(b) Control group					
Pre test	0	11	1	0	12
	1	2	2	0	4
	2	0	0	0	0
	Sum	13	3	0	16

improved their search performance from the pre- to post-tests significantly differed for the two groups ($\chi^2(1) = 4.13$, $p < .05$). This result indicates that the participants, who engaged in reflective activities supported by our instructional design, improved their search performance more effectively.

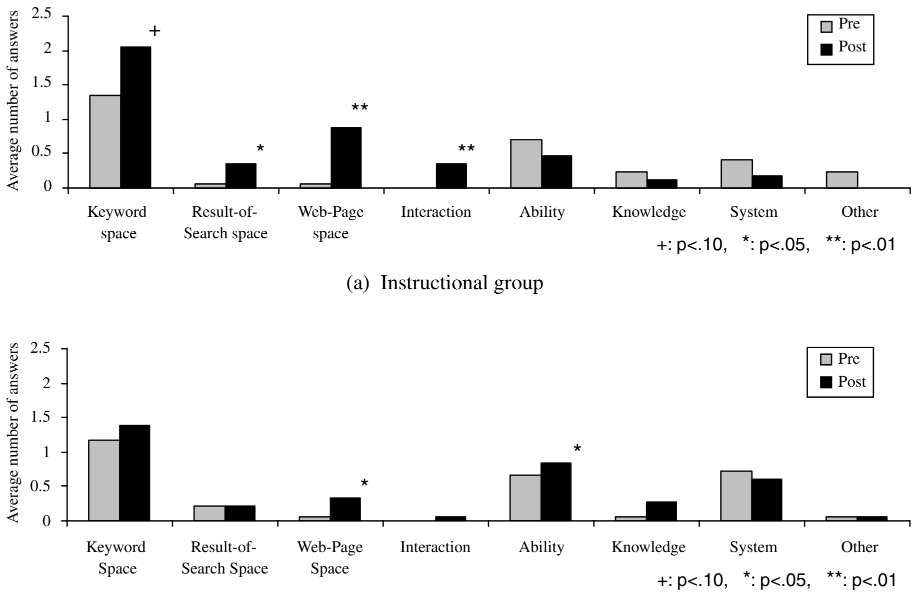
4.2. Important activities in information seeking on the Web

In the pre- and post-tests, the participants were asked to propose five activities that they considered important in information-seeking on the Web. The participants' answers in each test were categorized into the following eight types.

Keyword space: activities with search in the Keyword space.
Results-of-Search space: activities with search in the Results-of-Search space.
Web-Page space: activities with search in the Web-Page space.
Interaction: activities with transitions among multiple spaces.
Ability: necessities of abilities and attitudes.
Knowledge: knowledge required in information seeking on the Web.
System: functions of a search system, such as a search engine.

Fig. 6 shows the average number of items in each category in the pre- and post-tests. In the instructional group, paired t-tests indicated significant differences in the increase of the number of items in "Results-of-Search space" ($t(16) = 2.582$, $p < .05$), "Web-Page space" ($t(16) = 3.846$, $p < .01$), "Interaction" among spaces ($t(16) = 2.954$, $p < .01$) and a slight difference in the increase of the number of items in "Keyword space"($t(16) = 2.073$, $p < .10$).

The items above were related to the search processes on which the participants reflected. On the other hand, in the control group, paired t-tests indicated significant differences in the increase of the number of items in "Web-Page space" ($t(17) = 2.557$, $p < .05$) and "Knowledge" ($t(17) = 2.204$, $p < .05$). These results indicate that the participants who reflected on their search processes in the



(a) Instructional group

(b) Control group

Fig. 6. Average number of answers in each category in the pre- and post-tests.

instructional group acquired different notions as important concepts for the Web search than those in the control group; in particular, they realized their own search activities more profoundly.

4.3. Search processes

Finally, we discuss whether the participants' processes improved with our instructional design by comparing the pre- and post-tests in each group. In this study, we consider learners' information seeking processes as a cycle of search in the Keyword space and the Web space. This approach, where problem solving is considered to be a search for multiple spaces, has been widely approved in the studies on scientific discovery and creative processes. These studies have suggested that target activities are developed while repeating the cycle of searching multiple spaces. Therefore, we focused on the cycle of searching multiple spaces. We defined one search cycle as "a set of transitions from the Keyword space to the Web-Page space." We counted the number of search cycles in each task, and Fig. 7 shows the average number of search cycles in each group.

The number of search cycles was analyzed in a two-way mixed ANOVA with the group (the instructional/control) as a between-subjects factor and the test (pre-test/post-tests) as a within-subjects variable. There was a significant main effect of the test ($F(1,33) = 6.37, p < .01$), indicating that the number of cycles increased from the pre-test to the post-test. The Group × Test interaction was also found to show a trend toward significance ($F(1,33) = 3.07$, $p < .10$), which indicates that the participants in the instructional group more effectively increased the number of cycles than did in the control group. These results prove that the

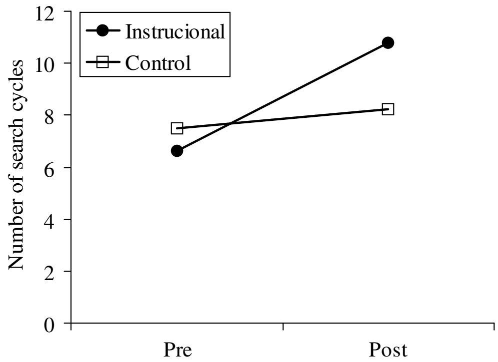


Fig. 7. Average number of search cycles in the pre- and post-tests.

participants in the instructional group searched two spaces more actively in the post-test than in the pre-test.

5. Discussions and conclusions

In this study, we proposed an instructional design that supports reflective activities by presenting learners' problem-solving processes in information seeking on the Web and evaluated its educational effects. We conducted an experiment to evaluate the effects of our design. Experimental results revealed that the participants' search performance in the instructional group improved more effectively than in the control group. Additionally, their ideas about important activities in information-seeking on the Web and that their search processes also changed from the pre-test to the post-test in comparison with the control group. These results indicate that our design helps learners improve their search performances and acquire search skills.

In this section, we discuss about association with the information literacy and contribution for studies on supporting reflective activities.

5.1. Association with the information literacy

The information search skill is regarded as one of the most important skills in information literacy. The American Library Association (ALA) Presidential Committee on Information Literacy (1989) defined information literacy as a set of abilities to recognize when information is needed and locate, evaluate, and use effectively the needed information. Additionally, the Association of College and Research Libraries (ACRL, 2000) and the Council of Australian University Librarians (CAUL, 2001) proposed information literacy competency standards for higher education to provide a framework for assessing students' information literacy skills. The standards consist of five basic competencies and twenty-two performance indicators. Among these standards, the second standard, "information literate student accesses needed information effectively and efficiently", is associated with the information search skill. The second standard features the following five performance indicators:

1. The information-literate student selects the most appropriate investigative methods or information retrieval systems for accessing the needed information.
2. The information-literate student constructs and implement effectively designed search strategies.
3. The information-literate student retrieves information online or in person using a variety of methods.
4. The information-literate student refines the search strategy if necessary.
5. The information-literate student extracts, records, and manages the information and its sources.

In our learning environment, the students are encouraged to learn the abilities for monitoring, evaluating, and modifying their own search activity. If students could perform these reflective activities spontaneously, they would be quite competent at satisfy the above five requirements.

Johnston and Webber (2003) reviewed the current state of education on information literacy, such as standards, models, and educational methods, in UK, USA and Australia. They referred to Hepworth's classification for teaching information literacy. Hepworth (2000) categorized approaches to teaching information literacy into two types. One is the discrete approach, where specific information literacy skills are taught in isolation. The other is the integrated approach, by which information literacy is integrated into the subject content of the discipline, such as project-based learning.

In this study, we focus on information-search activities that are associated with the specific information literacy skills. Therefore, our learning environment is regarded as a discrete approach. In the discrete approach, standalone instruction or practical training of specific information literacy skills are generally applied. In contrast, we provided a self-learning environment that helps students to acquire skills on their own initiative through reflecting on their own activities. Such reflective learning would be useful not only for the discrete approach, but also for the integrated approach.

5.2. Contribution for studies on supporting reflective activities

Finally, we discuss scaffolds in our instructional design. In this study, we focused on the process display, pointed out by Lin and Lehman (1999) to support learners' reflection on their problem-solving processes. Furthermore, they also proposed the following three scaffolds for reflective thinking:

Process prompts: prompting students' attention to specific aspects of processes while learning is in action.
Process models: modeling of experts' thinking processes that are usually tacit so that students can compare and contrast with their own process in action.
Reflective social discourse: creating community-based discourse to provide multiple perspectives and feedback that can be used for reflection.

Lin and Lehman (1999) suggested that it is important to incorporate all four scaffolds when developing designs because each method supports a different aspect of reflective thinking. We designed a learning environment in which learners could experience two types of reflection, such

Table 3
Multiple scaffolds in our instructional design

	Reflection in action	Reflection on action
Process display	○	○
Process prompt	○	×
Process models	×	○
Reflective social discourse	×	×

as "reflection-in-action" and "reflection-on-action", providing multiple methods for scaffolds referred by Lin and Lehman (1999) to support learners' reflective activities. Table 3 summarized types and methods of scaffolds in our design. In this paper, we empirically verified the effectiveness of combining these multiple methods for supporting reflective thinking.

Although many studies have suggested the importance of reflective activities, empirical studies for supporting learners' reflective activities have not adequately examined when and how to make students reflect on their learning. Moreover, the effect of reflection on training in information-retrieval skills has not yet been investigated. In this study, experimental results indicate the effectiveness of supporting two types of reflective activities, such as "reflection in information-seeking activities" and "reflection on information-seeking activities", and the availability of multiple scaffolds to support reflection, such as "process display" and "prompting". These findings could be applied to classroom settings.

Additionally, experimental results also imply that a cognitive schema is useful for not only analyzing human cognitive processes, but also supporting learning activities. However, we need to conduct further investigations on how each component in our educational design, such as a cognitive schema, "reflection-in-action," and "reflection-on-action," and above scaffolds, affects the learners' improvements.

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