Effect of Information Utilization Action on Engineering Design Based Problem Solving

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Children are expected to develop problem-solving skills, including 21st century skills. In Japan, the development of problem-solving skills is also considered important, and is particularly emphasized in the field of Information. Within the latter field, students are expected to develop the ability to utilize information and apply it to problem-solving activities. The IPS-I model has been developed as a concept that models such skills so as to gather information. However, the effect of information gathering and utilization on problem-solving has not been clarified. Therefore, this study investigates the effect of utilizing information on problem-solving action among high school students in Information. We conducted the group problem-solving activity and analyzed the dialogue between the participants. The results suggest that utilizing information activates discussion regarding problem-solving. In addition, it was found that groups with good problem-solving activity used the Internet to utilize information explicitly and in large quantities.

Keywords: Problem-Solving, Problem-Solving Activity, Information Utilization, Gather Information, IPS-I model

Introduction

Developing Problem-Solving Skills

Problem-solving skills are attracting attention as skills that need to be cultivated and are considered among the necessary skills of the 21st century (Griffin et al., 2012). Thus, many studies have been conducted to improve problem-solving skills. Recently, Engineering Design has been emphasized in the field of Science, Technology, Engineering, Arts, and Mathematics (STEAM) education (NRC, 2013). Ataman and Bursic (1996) investigated how problem-solving behavior changes when college students study engineering design. Here, they categorized problem-solving behavior and analyzed as the more the number of transitions in problem-solving behavior, the higher the quality of problem solving. They found that reading textbooks lead to more sophisticated problem-solving behavior. Mentzer et al. (2015) compared problem-solving action among freshmen studying Engineering Design, advanced students, and experts. The results indicate that first-year high school students were more attached to the first solution and had less time to generate ideas. Li et al. (2020) also showed that STEAM education with Engineering Design improves learners' problem-solving skills.

In England, the subject Computing has a similar content to Information. It is considered a weekly subject from elementary school to junior high school. It aims to foster computational thinking (Ofsted, 2022). In the United States, the CSTA Annual Conference (2017) exists with the goal of creating a unified curriculum for information education across the country, including the development of computational thinking and education on how to use science and technology to solve problems. In Japan, Information is identified as a subject that aims to improve students' problem-solving skills (Ministry of Education, Culture, Sports, Science and Technology (MEXT), 2018).

Developing Problem-Solving in Japan

The Ministry of Education, Culture, Sports, Science and Technology (MEXT, 2018) indicates that the goal of Information is to use information and information technology appropriately and effectively to discover and solve problems through learning actions that utilize information technology for problem solving. It requires students to develop the ability to effectively use information technology to discover and solve problems. Thus, it can be said that the cultivation of problem-solving skills is required in Information.

Based on this, practices aimed at improving problem-solving skills have been implemented in the field of Information in Japan. For example, Murai and Ito (2018) designed lessons aimed at improving problem-solving skills through a comparative study of Japanese textbooks. They found that learners' problem-solving awareness was improved through the use of spreadsheet software. Using an information system to develop problem-solving skills, Yoshida and Nakai (2020) created a design rights-related class and confirmed that learners' self-evaluations improved in terms of their knowledge, thinking ability, and attitudes toward learning.

Information Problem Solving

Research on information retrieval has also been conducted. Information problem solving (IPS) has been introduced as a concept that combines the skills needed to access and use information (Brand-Gruwel et al., 2017). The IPS-I model was developed as a model of the skills that students need to gather the necessary information on the Internet during the IPS process, consisting of five skills: (a) defining the information problem, (b) searching for information, (c) scanning information, (d) processing information, and (e) organizing and presenting information (Brand-Gruwel et al., 2005). Practices utilizing the IPS-I model have been conducted, demonstrating that the ability to search for information can be improved by teaching the IPS-I model (e.g., Strien et al., 2018). However, the main purpose of these activities is to collect information, and it is not clear how problem-solvers search for and use information during problem-solving activities.

To examine how information gathering affects problem solving, Mentzer (2014) also examined how restricting access to information when problem solving affects solutions. They found that the group with Internet access (versus without) spent the most time accessing it when solving problems; however, there were no significant differences between the two groups. It is important for learners to be able to gather the necessary information and use it to solve problems; however, it is unclear how they search for information and use it for that purpose. In this study, we define information utilization as the use of information that one already has or that one collects to solve a problem.

Purpose

This study aims to examine the influence of information search or information utilization action on problem-solving behavior. Therefore, the following research questions were explored:

1. Does the information utilization action during problem solving activities influence the quality of problem-solving action?
2. Does the use of information during problem solving activities influence the solutions generated?
3. Does the use of information during problem solving activities influence the solution decisions?

4. Does the volume of information accessed during problem solving activities influence the quality of the solutions?

The quality of problem-solving behavior is defined based on Atman and Bursic (1996). In this study, the higher the number of transitions in problem-solving behavior, the higher the quality of problem-solving behavior.

Methods

Participants

A total of 118 students taking information classes were selected for this study. The subjects were 80 high school freshmen in two classes and 38 high school sophomores in one class. None of them had received in-class instruction or activities for information retrieval. At the start of class, the subjects were asked to provide consent to collect the data, and if they did not consent to data collection, they were told that they would be excluded.

Problem-Solving Method

How do we describe the problem-solving methods taught to learners? In Japanese information, students are expected to deal with problems related to everyday life. It is said that the problems related to daily life can be handled by problem solving based on engineering design(NGSS, 2013). Therefore, in this study, we developed a problem-solving method focusing on engineering design.

From the perspective of Engineering Design (NGSS, 2013), problem-solving actions are divided into three categories: Define, Develop, and Optimize. Mentzer et al. (2015) revealed that novice learners are attached to a single solution. Therefore, to make the effectiveness of presenting multiple solution ideas when solving a problem easier to understand, this study divided the "Develop" category, which is summarized as a single problem-solving behavior, into two parts: "Develop," which is a problem-solving behavior to generate solution ideas, and "Select" which is a problem-solving behavior to select the best among multiple solution ideas. Thus, there are four problem-solving actions in total. The goals of each problem-solving behavior and the skills involved are listed in Table 1.

Table 1

Problem-solving method

Problem-solving action	The purpose of problem-solving	Problem-solving skills
Define	Define success conditions for solving the problem and constraints for what conditions are needed to solve it.	• Define the problem to be solved by considering the needs and challenges • Define the success conditions under which the problem can be solved by changing the problem • Define the constraints under which the problem must be solved
Develop	Generate a solution that is considered successful and satisfies the constraints that can solve the problem.	• Generate a solution that satisfies the success conditions for the defined problem • Generate multiple solutions that satisfy the success conditions from various perspectives
Select	From the proposed solutions, select the solution that is most likely to satisfy the success conditions under the	• Select the solution that best satisfies the success conditions from among the solutions generated • Check whether the selected solution captures

	constraints	the defined problem and constraints
Optimize	Optimize the solution such that when it is implemented, the results of implementation are enhanced in terms of effectiveness, efficiency, and attractiveness.	• Consider whether the selected solution could be made more effective, efficient, attractive, etc., and optimize it • Test the selected solution, collect data, consider whether there is anything that can be improved, and optimize it

Information Search Method

Information search action was established to guide the actions performed in information gathering. This practice involves gathering the necessary information to be used in a problem-solving activity, and the IPS-I model was used as a reference. Since it is difficult for learners to understand when many skills are presented simultaneously, we presented what we considered to be the most important skills. The goals of each information-gathering behavior and the skills included in each goal are listed in Table 2.

Table 2

Information search method

Information search action	The purpose of information search	Information search skills
Define the Information Problem	Identify what you are trying to search for	• Be specific in terms of the information you want to gather • Identify what you want to know
Search Information	Search for information using web pages	• Decide on search terms that apply to what you want to collect • Determine if the results displayed are what you want
Scan Information	Browse the web pages you have searched	• Read the content in detail • Decide if the content is appropriate for what you want to know
Process Information	Obtain information from the web page	• Determine if the information you have obtained is reliable
Organize and Present Information	Organize reliable and usable information from the information obtained	• Determine what information you can use from what you obtained

Information Utilization Skills

In this study, information utilization is defined as the use of information that one already has or that one has collected for problem solving. Therefore, it is necessary to instruct students on how to search for and use information in each problem-solving action. We clearly explained to the learners how to utilize the information in each problem-solving action category. Table 3 lists the actual instructions provided to the learners.

In this study, it is expected that learners will search information (Table 2) during problem solving (Table 1). The use of information obtained through information searching actions is defined as "information utilization skills" (Table 3).

Table 3

Information utilization skills

Problem-solving action	Information utilization skills
Define	• Search for what problems can be solved
Develop	• Search for solutions that will bring you closer to success
Select	• Find out what effect each solution would have if implemented
Optimize	• Search for examples of previous solutions in action • Find out what can be done to improve a problem that needs to be improved

Procedure

Figure1 shows the procedure of this practice. The practice was conducted in the classroom in February of 2023 over two consecutive days, lasting 50 minutes each day.

First, a class was conducted to teach problem-solving and information search/utilization methods, and the necessity of acquiring such methods was indicated to the learners. We then showed them the problem-solving and information search methods and instructed them on what skills they should acquire. In addition, we determined that it would be difficult for learners to learn and use each skill if they were only shown the skills, thus we provided prompts to support their use of the skills. The actual prompts are shown in Tables 4 and 5. Table 4 shows the problem-solving prompts created based on the problem-solving method (Table 1). Table 5 shows the information search prompts based on the information search method (Table 2). Then, to show learners how to utilize information during problem solving, we taught the information use skills in Table 3.

The participants then practiced using these skills through actual problem-solving activities. First, the participants practiced using the skills by working individually on problem solving for 10 minutes. Next, they had a 10-minute group discussion and practiced problem-solving in groups. The teacher checked whether the learners were able to utilize the information during problem solving by conducting desk-to-desk observations. Groups consisted of three or four students. It was decided that each group would always have a man and a woman student. Students were then assigned to each group using attendance numbers.

The following day, the students first reflected on the content of the previous class for about five minutes. As in the first day, each skill was briefly explained. In addition, specific examples of information utilization during problem solving on first day were presented. Subsequently, they worked in groups for 20 minutes on problem-solving activities. Students were required to work on problem-solving while discussing it in groups. As a problem-solving activity, the students were asked to plan a play activity, with the following is an example problem set: "You and your friends are going on a playdate. You want to go to a dolphin show as a place to go to together. In addition, they want to eat curry somewhere within 15 minutes of the aquarium. So, you meet at Tokyo Station and plan a play date that includes your friends' wishes."

This problem-solving activity was recorded. In addition, a worksheet was distributed to the learners, and they were asked to fill in the information they had used to solve the problem on a piece of paper and paste it on the worksheet. The information they had at the outset was written on yellow sticky notes, and the information they obtained from the Internet was written on blue sticky notes. The learners were then asked to fill out a worksheet with their final play plan.

After the problem-solving activity, the learners were asked to plan and peer-evaluate the play plans devised by each group. After listening to all groups' plans, they were asked to choose two groups that they thought were particularly good. They were also asked to write down any reason for their choice.

Finally, a post-questionnaire survey was administered to assess the problem-solving skills taught in this exercise and the prompts.

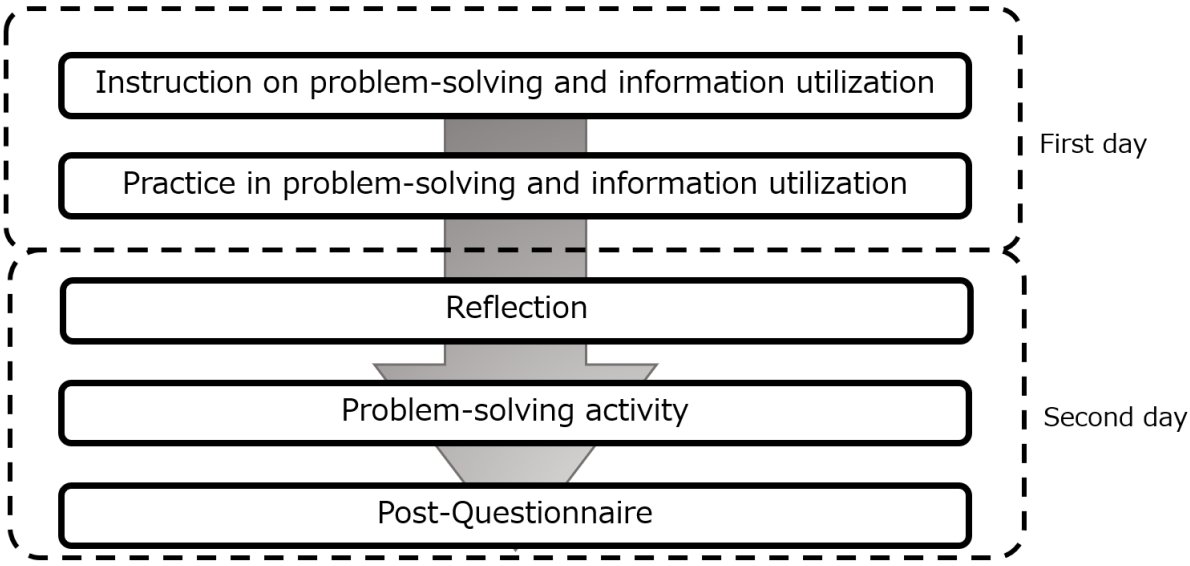

Figure 1. Research procedure

Table 4

Problem-solving prompts

Problem-solving action	Problem-solving Prompts
Define	• What is the problem to be solved? • What would be the success if the problem could be changed? • Are there conditions to consider when solving the problem?
Develop	• What kind of solution could bring the problem to a successful state? • What other solutions are possible?
Select	• Which of the solutions considered would come closest to the success condition? • Let's check if the solution is feasible!
Optimize	• Could the chosen solution be made more effective or efficient? • Can we test or predict the solution and see if there are any improvements?

Table 5

Information search prompts

Information retrieval behavior	Information search Prompts
Define the Information Problem	• What do you want to search for?
Search Information	• What search terms are appropriate for what you want to search? • Do the search results that are displayed contain what you want to know?

Scan Information	• Does the content of the page you see contain what you want to know?
Process Information	• Is the information you obtained reliable?
Organize and Present Information	• From the information you have obtained, summarize what you can use.

Data Collection

For the qualitative data portion, we collected recordings of the subjects' activities with iPad.

Analysis Guide

For group activities, based on the results of the peer evaluation, the groups were ranked in order of the number of votes received in each class. Subsequently, the difference in problem-solving behavior between the groups that received the highest number of votes and those that received the lowest was analyzed from the recorded data. Specifically, the process of problem-solving behavior and the influence of information-utilizing behavior on problem-solving was qualitatively investigated.

Results

Comparison of Groups' Solutions

The solutions were evaluated based on the results of a mutual evaluation. For mutual evaluation, each group was asked to present their play plans, and two groups were asked to vote for the plan they thought was the best. The results are shown in Table 5.

From the results, the top two groups in each class were the high evaluation groups (Group 3, 10, 18, 19, 26, 29), and the bottom two groups were the low evaluation groups (Group 1, 2, 12, 14, 23, 38, 30). The tendency for selection in the high evaluation group is that the solution was clear and the reason was written. In addition, other groups gave reasons for their evaluations, such as originality and a detailed plan. The solutions of the low evaluation groups tended to lack a clear purpose as to why they were planned.

Table 5

Results of mutual evaluation ranking

A class		B class		C class	
Group	rank	Group	rank	Group	rank
1	10	11	6	21	6
2	9	12	9	22	6
3	1	13	3	23	8
4	4	14	10	24	5
5	7	15	8	25	3
6	5	16	5	26	1
7	3	17	4	27	4
8	7	18	2	28	10
9	6	19	1	29	2
10	2	20	6	30	8

Differences in Problem-Solving Action

We analyzed the problem-solving activity referring to Ataman and Bursic (1996). They coded learners' utterances according to the content of their problem-solving action and measured the number of transitions. In their study, the group with the highest number of transitions performed better in problem-solving activity. Following this pattern, we coded the recorded data of group activities in this study and analyzed the types of problem-solving actions that were performed. Coding was based on Tables 1, 2, and 3. The information obtained by the learners was determined from the worksheet, whether it was existing knowledge or information obtained by using the Internet. Coding was performed by two people: the first author and a graduate student who majored in educational technology and had experience teaching information. First, after each of the authors coded, the areas of disagreement were discussed and a coding decision was made. The number of transitions in problem-solving actions was compared based on the coding results. The results are presented in Figure 2. Figure 2 shows the results of coding the first and lowest classes of a given class.

High Evaluate Group 1

Time(minute)					1				2				3			
Problem-solving action	Define	Develo	Define	Develo	Define			Develop			Develo	Develop		Select	Select	Define
Information utilize											Utilize					
Time(minute)	4				5				6				7			
Problem-solving action	Develo	Develo	Develop		Select	Select			Define	Develop			Define	Develop		Develop
Information utilize		Utilize	Utilize		Utilize	Utilize										
Time(minute)	8				9								11			
Problem-solving action				Develo	Define	Select		Develop			Select	Select	Define	Define		Select
Information utilize								Utilize						Utilize		
Time(minute)	12				13				14							
Problem-solving action	Select	Define	Select	Select	Select		Sekect	Select	Select		Optimi	Optimi	Select		Select	Define
Information utilize	Utilze														Utilize	
Time(minute)	16				17				18				19			
Problem-solving action	Select	Select	Select	Define	Define		Select		Optimize			Optimi	Optimi	Optimize		
Information utilize					Utilize		Utilize		Utilize			Utilize	Utilize	Utilize		

High Evaluate Group 2

Time(minute)					1				2				3			
Problem-solving action					Define		Define	Develo	Develop							
Information utilize									Utilize							
Time(minute)	4				5				6				7			
Problem-solving action	Develo	Develo	Develo	Define	Develo	Develop		Develo	Develo	Select			Define	Select	Define	Optimze
Information utilize	Utilize	Utilize			Utilize			Utilize	Utilize							
Time(minute)	8				9								11			
Problem-solving action	Optimize		Define						Define	Develo	Optimi	Define	Optimi	Define	Develop	
Information utilize													Utilize			
Time(minute)	12				13				14							
Problem-solving action	Optimi	Select		Define	Develo	Optimi	Optimi	Develo	Develo	Select	Develop		Develop		Define	Select
Information utilize							Utilize		Utilize	Utilze						Utilize
Time(minute)	16				17				18				19			
Problem-solving action		Develo	Define	Select	Select	Select	Select	Select	Select	Select			Optimize			
Information utilize				Utilize												

Low Evaluate Group 1

Time(minute)					1				2				3			
Problem-solving action		Define	Develop			Develop					Develop				Develop	
Information utilize											Utilize					
Time(minute)	4				5				6				7			
Problem-solving action		Develop									Develop					
Information utilize											Utilize					
Time(minute)	8				9								11			
Problem-solving action		Define	Define	Develop			Select	Develop		Develop		Develop		Define	Develop	
Information utilize							Utilize								Utilize	
Time(minute)	12				13				14							
Problem-solving action	Define		Develop			Develop					Optimize			Select		
Information utilize			Utilize			Utilize										
Time(minute)	16				17				18				19			
Problem-solving action						Optimize										
Information utilize																

Low Evaluate Group 2

Time(minute)					1				2				3			
Problem-solving action					Define	Develo	Define	Develp		Develop		Select		Develop		
Information utilize								Utilize								
Time(minute)	4				5				6				7			
Problem-solving action					Develop									Develo	Develop	
Information utilize																
Time(minute)	8				9								11			
Problem-solving action	Develop						Define	Develo	Develo	Define	Select	Define			Select	
Information utilize	Utilize							Utilize								
Time(minute)	12				13				14							
Problem-solving action	Select		Develo	Select	Develop				Select	Select						
Information utilize																
Time(minute)	16				17				18				19			
Problem-solving action				Define	Define				Select					Select	Select	
Information utilize																

Figure 2. Problem-solving action

Relationship between Information Utilization and Problem Solving

Qualitative differences in problem-solving action between the high and low evaluation groups were examined. When the high evaluation group utilized information for problem solving, they not only used the information they have but also information they obtain from the Internet. Specifically, they tended to use the Internet for information research and utilization when performing the problem-solving actions of "Develop", "Select", and "Optimize".

When performing the problem-solving action of "Develop", the high evaluation group was found to collect information using the Internet in addition to generating ideas for proposed solutions based solely on their existing knowledge. Table 6 shows examples of dialogues of similar situations found in three or more groups.

Table 6

Conversation content for "Develop"

Person	Content
A	I looked up a place called KK by the YY station.
B	Is that a good place?
A	There's also a place called LL.
C	Is there any other place that's a little bit different?
A	There's also a place called MM.
B	That place looks good!

In addition, when performing the problem-solving action of "Select", the high evaluation group also used the Internet more to search for information when deciding on a solution. They compared the solution ideas they generated with the conditions they wanted to satisfy in their definitions and talked about searching to see which idea satisfied them the most. Table 7 shows examples of dialogues of similar situations found in three or more groups.

Table 7

Conversation content for "Select"

Person	Content
A	Which store would be better?
B	Isn't this store closer to you?
C	Isn't it more efficient because I can definitely put it on within 15 minutes?
A	Is KK better?
B	No, MM is closer.
B	And the curry is better!
D	So MM has better conditions than KK.

We observed that once a solution was determined, the high evaluation group searched for information to see if there were any ideas that would better satisfy the conditions identified in the definition of the solution. Table 8 shows examples of dialogues of similar situations found in three or more groups.

Table 8

Conversation content for information research

Person	Contents
A	Let's go to XX Aquarium.
B	Then, we need to know how long it will take from YY station to XX Aquarium.
C	That's right.
B	It would be better to know how long it will take, right?
A	Yes, I think so.

Person	Contents
D	Do you know what time the dolphin show is? You wouldn't know, would you?
E	I might know.
D	Well, can I ask you to check?
E	Sure, just give me a minute.

Results of the Post-Questionnaire

The effectiveness of the problem-solving prompts, information retrieval prompts, and information use skills used in this study were evaluated. The results are summarized in Table 9.

Table 9

Results of the Post-Questionnaire

No	Contents	*M*	*SD*
1	It was easier to think when I worked on problem-solving by referring to the questions	4.42	0.65
2	It was easier to search for information when I used the questions as a guide in solving the problem	4.50	0.64
3	It was easy to use information when I worked on problem solving referring to the questions	4.43	0.65
4	I was able to think properly about problem-solving, whereas I used to do it only casually	4.34	0.69
5	I think I can now think properly in areas where I used to just casually search for information	4.37	0.69
6	I think I am now able to think properly in areas where I used to just sort of utilize information	4.35	0.68

n=118, 5 Likert scale

Discussion

Does the information utilization action during problem solving activities influence the quality of problem-solving action?

Table 2 results show that the number of transitions in problem-solving behavior was higher in the highly rated group. This suggests that the high evaluation group was able to perform a higher quality series of problem-solving behaviors, referring to the analysis by Ataman and Burisc (1996). Figure 2 also shows that the high evaluation group performed more information utilization behavior. From the above, the information utilization behavior is considered to be one of the reasons for the high quality problem-solving behavior.

One of the reasons for the higher number of transitions in the solution may be the repeated definition of the solution when it was proposed as the basis for the solution. The actual dialogs confirm that when the participants were thinking of solution ideas, they returned to the definition once to check what kind of solution was required and what kinds of restrictions existed. This activity was common in the high evaluation group.

Does the use of information during problem solving activities influence the solutions generated?

Table 6 shows that the participants are utilizing information when they are engaged in problem-solving behavior. This suggests that they are using the Internet to collect information and utilize it to generate solutions. Specifically, the participants were talking about organizing success and constraint conditions based on definitions, and utilizing information to generate solution ideas that meet those conditions.

Does the use of information during problem solving activities influence the solution decisions?

Table 7 shows that the participants are utilizing information during the problem-solving behavior

of selecting a solution. This suggests that they utilize information when deciding on a solution. Specifically, when comparing the generated ideas and making a decision, the participants were utilizing information on the evidence that matches the success and constraint conditions organized in the definition.

Does the volume of information accessed during problem solving activities influence the quality of the solutions?

The above results indicate that information is utilized during problem-solving behavior. Although we knew how information was utilized during problem solving, we did not measure the extent to which information was actually accessed. Therefore, it was not clear to what extent the quantity of information retrieval was involved in improving the quality of problem-solving behavior. However, Table 8 suggests that the group with the most information utilization behavior may be the highly evaluated group. We would like to clarify the relationship between the quantity of information retrieval and the difference in the quality of solutions through further investigation.

Conclusion

It was confirmed that there were differences in the problem-solving and information utilization behavior between the group that received high evaluations for problem-solving and the group that did not. The highly rated group had a higher number of transitions in problem-solving behavior than the low rated group. Ataman and Bursic (1996) showed that the number of transitions of problem-solving behavior is related to the quality of problem-solving behavior. Therefore, it was suggested that the high evaluation group was able to perform higher quality problem-solving behavior than the low evaluation group. In addition, it was found that the high-evaluation group used the Internet more to search for information when they used the information necessary for problem-solving. And, the information utilization action influenced the generation of solutions and when making decisions. The high evaluate group engaged in more information utilization action and utilized it to solve problems. In other words, the results suggest that information utilization action improves the quality of problem-solving behavior.

One of the reasons why information utilization did not appear in the problem-solving action of "Define" is that the subject matter used in this study did not require information research. The main piece of information used in this definition was a play request from a friend. Therefore, it is thought that the participants tended to judge that they had enough information to solve the problem without searching on the Internet.

We found that learners responded well to the prompts we used in this study. Because problem solving is a higher-order skill, prompts that reduce the learner's effort are more effective than those that simply teach the skill.

In this study, we obtained a suggestion about the relationship between information utilization behavior and problem-solving behavior. However, the relationship between the actual amount of information retrieval and problem-solving behavior is not known. Therefore, it is meaningful to investigate the relationship between the amount of information retrieved from the Internet and problem-solving behavior in future research. On the other hand, simply searching information is also inefficient. It is necessary to teach how to identify the most useful information.

This study has several limitations. First, we did not observe what kind of retrieval was actually performed, since what was said during the problem-solving activity was the information that was

actually used in the group problem-solving behavior. However, it is possible that the problem-solving behavior did not succeed because the information retrieval did not succeed or because the information they wanted was unavailable. As we were not able to observe whether they obtained the information they truly needed to solve the problem, further research is needed in the future.

Second, the problem used in this study was set as a familiar problem to the learners, and the difficulty level was set at a level that would allow them to solve the problem in a 20-minute time frame. It is not certain whether the same results will be obtained when solving more complex questions that are needed in society. Therefore, there is a need for investigating problem-solving situations using more subjects.

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