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Effective Knowledge Reinforcement in Networked Cooperative Work Based on Symbiotic Computing: Basic Concept and Its Application

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In this paper, we propose a scheme to effectively support cooperative works by controlling information flow from real space (RS) to digital space (DS), and from DS to RS, based on the concept of "Symbiotic Computing." In practice, our scheme controls availability of shared workspace in DS for cooperative works, according to the situation of tasks and workers in RS, in order to accelerate cooperative works, along with reinforcing "value placed on information." Using this scheme, advanced support to improve quality of intellectual cooperative works can be realized. In this paper, we apply our proposed scheme to group learning domain. This is an educational activity domain where group members including a teacher and several students cooperatively solve the given problems. Applying to this domain, we show that the proposed scheme, i.e., suitable availability control of shared workspace in DS, can accelerate the cooperative works. From experiment results, we found that the cooperative problem solving by teacher and students were accelerated. Also we confirmed that the learning outcomes were improved, by controlling availability of the shared workspace, according to the progress of the group learning process. From these results we evaluated the effectiveness of our proposal.

KEYWORDS: Symbiotic Computing, Group Learning, Cooperative Work, Multiagent System

1. Introduction

Recently, with rapid growth in computer and network technologies, researches on supporting intellectual cooperative works using information communication technology (ICT) are being promoted actively. In practice, many kinds of networked cooperative work support systems, by which users can share information resources and related tasks on network environment, have been developed so far [1, 2]. The objective of these systems is to accelerate process of cooperative work among group members who physically exist in a distance. Examples of these systems are cooperative CAD system, support system for project-based software development, cooperative editing system, distance e-Learning system, etc [3–5]. Using traditional cooperative work support system, group members can pursue their jobs as if other members are physically close to them, even if they actually are in a distance. With this system new class of work style such as "telework" is emerging. This trend has potential to change structure of human society.

From functioned viewpoint of networked cooperative work support system, it mainly focuses on how to effectively share and access to the information resources and tasks on network environment. That is, in traditional support system, it contributes only to collect "data" needed in the cooperative works, to aggregate/organize the data as "information," and to provide the tailored information to group workers. Thus, it does not directly contribute to reinforce "value placed on information." In other words, the system is just a substitute of paper media, and it does not do for improvement on intrinsic quality of the cooperative work. Moreover because the information is accumulated on network in chaotic manner, it is getting harder to find and control needed information. This is called as "deluge of information" problem. Therefore expectation is increasing to the advanced and secure support system for cooperative works that contributes to greatly improve quality of cooperative work itself.

We consider that recent problems in IT society such as deluge of information and digital divide, originate gaps between real world (Real Space: RS) and virtual world constructed on computers and networks (Digital Space: DS). We call these gaps "u-Gaps." To bridge the u-Gaps, we have proposed the concept of "Symbiotic Computing" [6–10]. This computing aims to bridge the u-Gaps by mutual understanding between real space RS and digital space DS.

Here let's reconsider recent cooperative work support systems in accordance with the basic concept of Symbiotic Computing. Information and environmental data needed for the cooperative work in RS, can be effectively acquired using many kinds of sensor technologies. On the other hand, information in DS can be provided to users in RS by employing Web computing technologies. Thus, required information for cooperative work accumulated in DS, is structured to increase accessibility, and then it is given to users in RS. However, flows of data/information from RS to DS and from DS to RS are independent, and mutual relationship between the flows is not strong. Therefore, flow control of data/information according to activities of users in RS does not work, and required information for cooperative work would not be provided to group members in RS when the need arises. This is a typical example of u-Gap problem in networked cooperative work support systems.

To address the above problem, we propose a scheme to effectively support the cooperative works to reinforce "value placed on information" by controlling information flows from RS to DS and from DS to RS. This scheme is based on the concept of mutual understanding between RS and DS in Symbiotic Computing. In practice, we control availability of shared workspace for cooperative works in DS, according to the situation of tasks and workers in RS, in order to accelerate proceeding of the cooperative works. When the shared workspace is not available, workers can concentrate on their own tasks to increase their personal ability. After that the shared workspace becomes available, the given task will be proceeded by cooperative work of group members. By switching these phases alternately in right timing, the value placed on information in DS is reinforced. Then the information would be actively fed back to RS as "Knowledge," and advanced support to increase quality of intellectual cooperative works can be realized.

In this paper, we apply our proposed scheme to group learning domain that is one of the intellectual cooperative works. The group learning is an educational activity domain with group members including a teacher and several students. The students cooperatively solve give problems according to the teacher's advices. Applying to this domain, we show that the proposed scheme, i.e., suitable availability control of shared workspace in DS, can accelerate the cooperative works. From experiment results, we found that the cooperative problem solving by teacher and students were accelerated. We also confirmed that the learning outcomes were improved, by controlling availability of the shared workspace, according to the progress of the group learning process. From these results we evaluated the effectiveness of our proposal.

2. Symbiotic Computing: The Concept

2.1 Concept of Symbiotic Computing: Mutual Understanding between Real Space and Digital Space

When people in real space (RS) are to receive services in digital space (DS), but they are disturbed and can not receive it enough, the disincentives are called "u-Gaps." Recent problems of IT society such as digital divide and deluge of information are the examples of the u-Gaps. So far, a huge amount of social capital has been invested in technology, human, and finance in order to build digital space, and we have expected its great effect. However it does not lead enough to restore vitality to the local community and to raise international competitiveness. This is due to the fact that we have neglected development of the technology to bridge the u-Gaps.

To address the u-Gap problems, it is important to understand other people's situation, that is, to realize "mutual understanding" between RS and DS [6, 7]. This mutual understanding consists of RS recognition and DS recognition as shown in Fig. 1. RS recognition is a notion that DS autonomously acquires social knowledge, individual characteristics, environmental information of RS, etc. In contrast, DS recognition is a notion that DS presents and offers information, knowledge, and services in DS to RS properly and in an understandable way. As mentioned above, mutual understanding is a state where RS and DS become aware of each other.

DS autonomously acquires, for example, information of RS from computer, sensor network, and mobile devices in RS, and recognizes human activities in RS. After understanding the requirements and intentions of people in RS, DS

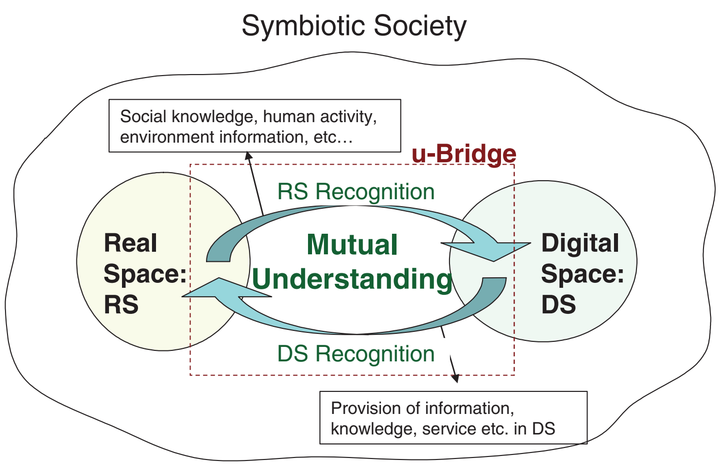

Fig. 1. Concept of symbiotic computing: mutual understanding between real space RS and digital space DS.

actively provides RS with appropriate information, service, and knowledge. Such a mutual understanding between RS and DS is critical to address the u-Gap problems.

Compared with RS which has been active, whereas DS is passive. Symbiotic Computing is a computing method to create autonomy in DS and realize mutual understanding between RS and DS.

2.2 Effect of Symbiotic Computing on Cooperative Works

Here we consider the u-Gaps in supporting cooperative works in detail.

Traditional DS has been passive. This means that DS provides information to RS only when people in RS require the information. Or DS indiscriminately gives information to RS in everytime and at everywhere without any consideration of status of RS. For people in RS, this leads to unwanted situation. For example, if necessary information for cooperative works is not provided in good timing, indiscriminate circulation of unuseful information put the progress of the works to a halt. This would be a disincentive that makes cooperative works inefficient. This is one of the examples of e-Gaps.

Mutual understanding between RS and DS by Symbiotic Computing will recover this unwanted situation. Using this concept, DS can provide information autonomously and effectively to RS. This makes increase of value placed on information in DS and also makes great progress of cooperative works through DS.

In concrete, necessary and sufficient information can be provided only to people in RS who require the information, only when it is needed. This can be done because DS recognition in Symbiotic Computing considers situation of RS. This brings deletion of the disincentive in intellectual activities of people in RS. Moreover, we can get outcomes of works in RS onto DS and share it by group members of cooperative work by recognition of RS. Using this recognition, value placed on information is amplified and the information can effectively be fed back to works in RS. The reflux flow of information between RS and DS can be expected to make a great improvement in quality of cooperative work of people in RS.

3. Proposal: Controlling Availability of Knowledge Fields Based on Situation of Cooperative Work

3.1 Knowledge Fields

Based on the concept of Symbiotic Computing, information acquired and accumulated in DS is fed back to RS. Then it is used for intellectual cooperative works by people in RS and is returned to DS. As the information refluxes between RS and DS, with human and computation processing, it becomes valuable in stepwise manner. We call the information that is dynamically changed by refluxing between RS and DS, as "Knowledge."

Here we define a workspace where knowledge is processed as a Knowledge Field. In the Knowledge Filed, human workers and computational processes operate the knowledge. The knowledge transits to higher level by the operation. There are two kinds of the Knowledge Fields: Personal Knowledge Field (PKF) and Shared Knowledge Filed (SKF). The concept of PKF and SKF is shown in Fig. 2.

A PKF is a personal workspace given for each users. Examples of the PKF are physical personal note, word processor, text editor in computer, design support system for a specific task, etc. Each user works individual tasks in his/her PKF and stores the outcomes of the tasks there as knowledge.

On the other hand, A SKF is a shared workspace in DS. It is used for cooperative works by group members. Examples of the SKF are physical whiteboard, networked shared editor, groupware for a specific task, etc. In the SKF,

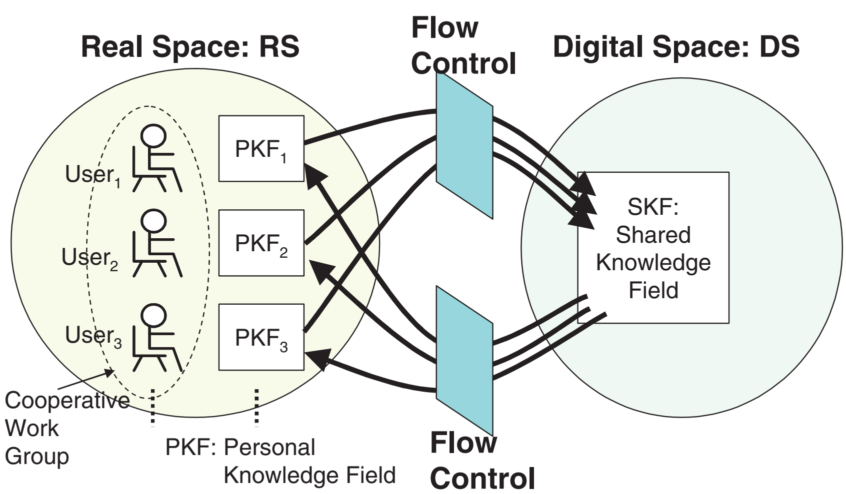

Fig. 2. Effective knowledge reinforcement by controlling availability of Knowledge Fields.

outcomes of works from PKF are aggregated as shared knowledge. Then cooperative workers discuss about the knowledge, operate on the knowledge with their agreements, and change it to much higher level.

3.2 Controlling Availability of Knowledge Fields

In this paper, we propose a scheme to effectively support to increase quality of intellectual cooperative works by controlling availability of the Knowledge Fields.

In traditional cooperative work support system, SKF is always shown and available. The workers can do the cooperative works everytime by using the SKF. However, there is a case that tasks occurred in SKF prevent each user to concentrate on tasks in PKF. This brings interrupt on knowledge reinforcement in the PKF. In this case, total quality of the cooperative work is degraded.

To solve this problem we propose a scheme to maintain knowledge flow between PKF in RS and SKF in DS, by controlling availability of SKF. Using this scheme, tasks in PKF are not interrupted during personal work phase and knowledge in PKF is amplified effectively. Moreover, the SKF gets available when tasks in each PKF progress to a required level. Then the outcomes are uploaded and merged onto SKF, and the work transits to the cooperative phase. After sufficient discussion and cooperative works in SKF, the results of works in SKF are downloaded onto each PKF and personal work goes ahead. Reputation of this switch between works on SKF and PKF, knowledge reaches to much higher level.

To summarize, in this scheme, we do not always provide SKF in every moment, but we consciously restrict the availability of SKF according to situation of progress of cooperative works in both Knowledge Fields. By switching between work phase in SKF and that in PKF properly, the cooperative work progresses smoothly, and as a result, total quality of outcomes of the work is expected to be greatly improved.

4. Design and Implementation of Evaluation System for Proposed Knowledge Field

4.1 Functional Requirements Analysis

We describe design and implementation of evaluation system which realizes effective knowledge reflux between Shared Knowledge Field (SKF) and Personal Knowledge Field (PKF) and is used to verify effectiveness of proposed method. At first, we analyze functional requirements. In order to realize proposed SKF control, following two main functions are needed. One of them is a function to share information among users who carry out cooperative works. The other is a function to make SKF enabled or disabled according to condition of the cooperative works. In this paper, we focus on hand-drawn picture as shared information, and design a whiteboard system which make the picture shared among users using network, i.e. this system provides shared picture as SKF. Here, while existing whiteboard systems are generally share a picture full-time, we realize a function to enable and disable SKF according to condition of works to satisfy the functional requirements mentioned above. Additionally, to make users able to carry on their own works while SKF are not provided, PKF drawing function is also needed.

With above mentioned analysis of functional requirements, functions to be implemented into our evaluation systems are as follows:

- Drawing function of shared picture (SKF).
- Changing function to enable and disable shared picture.
- Drawing function of personal picture (PKF).
- Copy function between shared and personal pictures.
- Management function of Attendee name.

4.2 Agent oriented Design

To design the above mentioned five functions, we utilize an agent oriented network middleware: AMACS which is our previous work. AMACS has functions of communication channel establishment based on user name, automatic service construction both originator and answer terminals and so on. The functions make design of our evaluation system much easier. Figure 3 shows agent structure of the evaluation system. Ovals in the figure indicate agents which compose the system. And there are two kinds of agents. One is an AMACS Core agent which realizes basic function of AMACS, and the other is an Application Agent which realizes required function of our evaluation system mentioned above. Details of these agents are described below.

4.2.1 Application Agents

SharedBoardClient This is an agent which provides GUI for drawing function of shared picture and personal picture. We designed several drawing tools, which are line, circle, eraser, copy between shared and personal pictures, save and load to/from external file and pointing tool on shared picture. Drawing actions from user to shared and personal pictures are sent to SharedBoardServer agent described below. And also, drawing actions received from SharedBoardServer are reflected in shared picture. Additionally, this agent enables and disables shared picture according to the order of SharedBoardServer.

SharedBoardServer This agent distributes drawing actions received from SharedBoardClient to any other

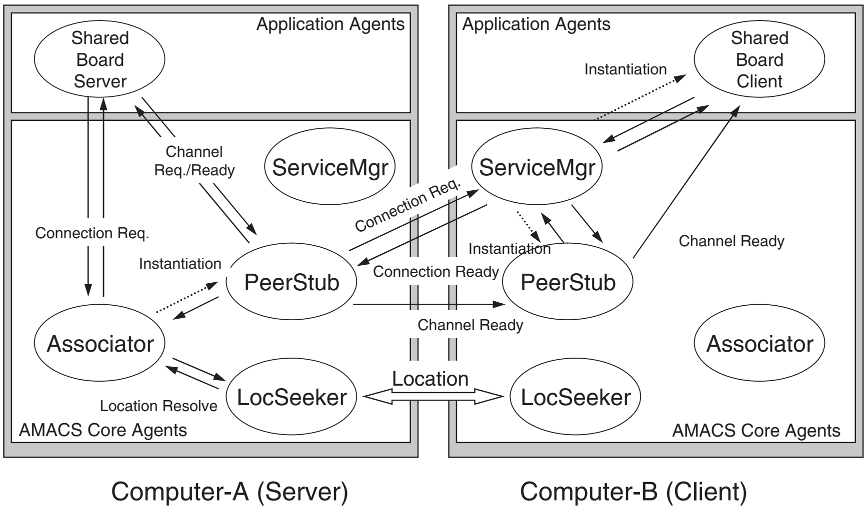

Fig. 3. An agent structure of evaluation system.

SharedBoardClients. Also this agent has a live monitoring function which receives personal pictures from all SharedBoardClients and provides them for a group leader, i.e. a user using this agent. Additionally, this agent has a function to send orders to enable and disable shared picture to SharedBoardClients all together.

4.2.2 AMACS Core Agents

LocSeeker This is an agent which advertise a user's name and its own IP address to network. This agent also keeps advertisements received from other LocSeeker and provides received users' names to their own users.

Associator, ServiceMgr These agents realize communication channel requirement acquisition function. Associator accepts a communication channel requirement from agents on local host. The requirement consists of destination user and desired service name. Once Associator receives the requirement, it queries IP address of a destination host which destination user is currently using to LocSeeker, and requests communication channel establishment to ServiceMgr on the destination host.

PeerStub PeerStub establishes a communication channel for application data between SharedBoardServer and SharedBoardClient.

4.3 Implementation

According to design mentioned above, we implemented a prototype system. Figure 4 describes an implementation environment. We connected a DesktopPC for GroupLeader which runs SharedBoardServer, three LaptopPC for GroupMembers which run SharedBoardClients. A Pen Table is connected to each LaptopPCs for hand-writing. Operating system is Microsoft Windows XP, and Java is used for implementation language. Additionally, we used DASH [11], which is developed by us, as an agent framework.

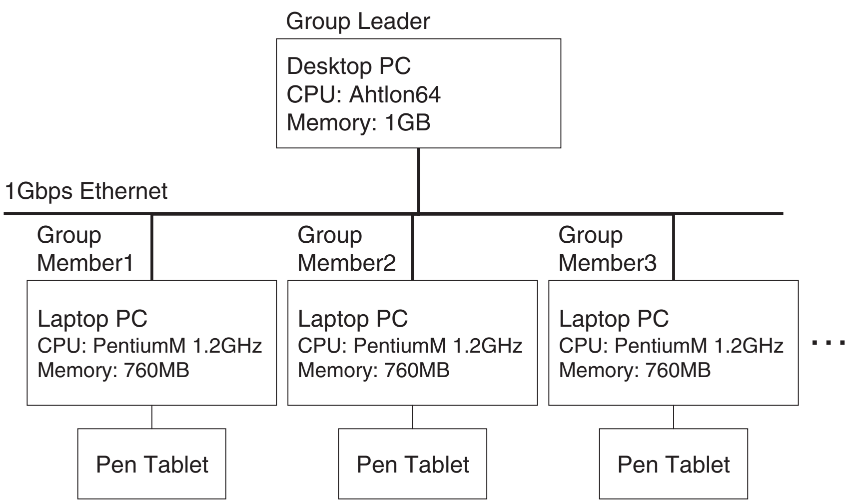

Fig. 4. An implementation environment.

5. Application to Group Learning and Experiments

5.1 Applying to Group Learning Domain

In this paper, in order to evaluate the effectiveness of this proposed method, we focus on group learning consists of a teacher and several students as a specific example of cooperative work on a network. With this group learning, we confirm the result achieved by applying this method.

Group learning is a task domain of intelligent cooperative work for the purpose of education of students [1–5], in which each student in a group acquires knowledge effectively with exchanging information with a teacher and other students. The information exchanged here includes conversations between teacher and students (advice and question), contents of the problems to be solved, solving method, examples of solutions, and so on. While exchanging and sharing such information, participants work cooperatively toward study goals such as "to solve a given problem." This cooperative work realizes advancement of each student's knowledge.

In group learning, generally, it is effective for each student to study by oneself and discuss with group members alternatively over and over. Through self-study, every single student will be able to develop one's ability of thinking. In addition, through the group discussion utilizing the result of the self-studying, each student will be able to learn other solving methods from ones he/she finds and resolve the points of difficulties during self-studying. As a result, whole study of the group will proceed. Thus, both self-study and group discussion are important, and if they are executed alternately at an appropriate moment, the effect of group learning will be enhanced radically.

Based on the basic motivation mentioned above, in this paper, we apply the proposed method, "Effective Knowledge Sharing with Controlling of Knowledge Field," to this group learning domain. Specifically, we provide respectively the PKF (Personal Knowledge Field) as an environment for self-studying and the SKF, which is shared on a network, as a space for group discussion. Here, we expect group learning to proceed effectively by shifting current space between PKF and SKF appropriately in response to the progress of the study.

As a specific group learning, in this paper, we deal with a task where several students solve a problem given by a teacher with multiple solving methods. More specifically, at first, a teacher poses a problem as an assignment to a group, and each student in the group finds its solving method utilizing one's PKF. Next, in a group discussion phase, each student presents one's works done in the PKF to a SKF, and while communicating with the each other, group members study on the works. Then, again, each student shifts to one's PKF and proceeds with the self-studying. The group learning will proceed by executing this process repeatedly.

The specific goal of this group learning is to find solving methods of a problem in as many way as possible, and we can evaluate the effect of the group study quantitatively with the number of solving methods found by the end.

5.2 Purpose of Experiment

For the purpose of evaluating the effectiveness of the proposed method, we conduct an experiment, applying this method to group learning domain as we mentioned in the last subsection.

Specifically, we develop a system for supporting group learning with the system we mentioned in Section 4. By utilizing the supporting system, we perform an experiment in which a teacher and students carry practical group learning activity on real system. After that, based on process and result of the study and analysis of questionnaire answered by the participants, we evaluate and examine the effect of this proposed method.

5.3 Experiment Method

Here, we describe the steps of this experiment.

On one session, one teacher and three students carry group learning on one problem which has multiple solving methods. The work duration for each session is 20 minutes, and the goal is to find solving method of the problem as many as possible within this time.

In this experiment, not automatically, but a teacher and students shift the PKF and SKF by determining from the progress of the study. In order to evaluate the effect of shifting the PKF and SKF, we conduct the experiment with three types of systems; S1, S2, and S3, as follows.

1) A system which always presents both the PKF and SKF without shifting (existing scheme: S1).
2) A system which shift the PKF and SKF.
   2-1) on response to the request from students (proposed scheme 1: S2).
   2-2) on response to the request from a teacher (proposed scheme 2: S3).

We carry the experiment twice with each type of system as mentioned above. In each time, group members solve two math problems related to geometry as follows:

(P1) A problem to calculate the area of a triangle.
(P2) A problem regarding a circle and a tangent line.

We adopt graduate students as examinees. As one group can carry only one session on one problem, we can not allot more than one system to a group for our evaluation. Thus, we respectively allot different examinee groups, G1, G2, and

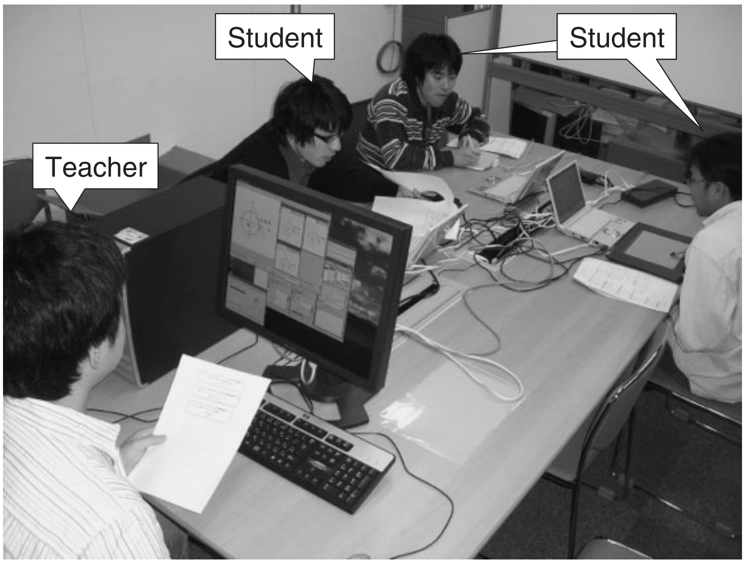

Fig. 5. A snapshot of the experiment.

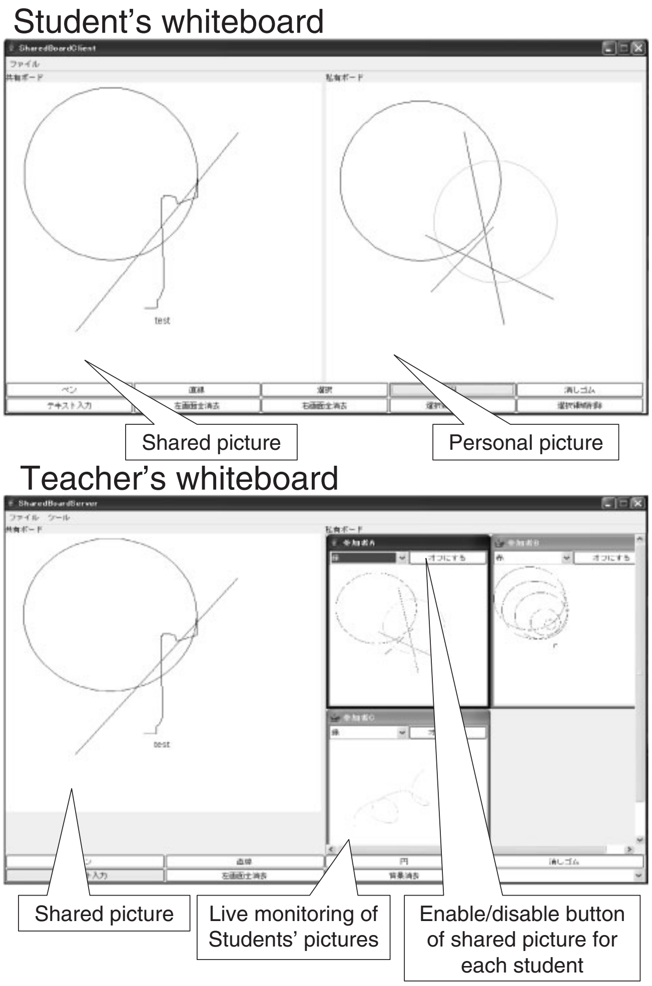

Fig. 6. U/I of group learning support system in the experiment.

G3 to the three types of the system, S1, S2, and S3. In other words, a group Gi was allotted one type of system Si, and the group members will solve two problems, P1 and P2, with the type of the system.

Figure 5 shows the snapshot of the experiment.

Figure 6 shows an example of the user interface of the support system.

5.4 Measures of Evaluation

We evaluate the result of the examination with measures as follows.

(1) Quantitative Evaluation on the Effect of the Group Learning: We evaluate the effect with number of solving methods each group finds.

(2) Subjective Evaluation on the Effect of the Group Learning by Teacher and Students: We evaluate the effect with questionnaire, the questions being as follows.
[For student]
1) Did the intergroup communication go smoothly?
2) Were you able to communicate with the teacher smoothly?
3) How many solutions did your group find?
4) Were you able to solve the question in cooperation with the other students?
5) Is there any deadlock state during the session?
6) Is there any stagnant state during the session?

[For teacher]
1) Were you able to communicate with the group smoothly?
2) Were you able to communicate with each student smoothly?
3) Were you able to instruct each student properly?
4) Was it easy to handle the group learning as a teacher?
5) Is there any deadlock state during the session?
6) Is there any stagnant state during the session?

6. Experimental Results and Evaluation

6.1 Overview of Experimental Results and Evaluation

Experimental results are shown in Table 1 to Table 5.

Table 1 shows number of solutions which at least one student could make it to as a result of group learning for each question of (P1), (P2) and each situation of (S1), (S2) and (S3).

Table 2 from Table 5 show results of questionnaires which are carried out by teacher and all students after each trial. Each number in these figures indicates average of evaluated values for each questionnaire item. Each value can take 1 to 4, 1 means lowest and 4 means highest.

Table 2 shows summary of questionnaire for question (P1) from the students and the corresponding answers, and also Table 3 shows the same from the teacher.

Also Tables 4 and 5 shows summaries of questionnaire for question (P2) from students and teacher respectively.

In the following sections, we evaluate the above results from the view points of actual achievement of group learning, communication between students in group learning, communication between student and teacher and procedure of group learning.

Table 1. Number of acquired solutions compared with traditional system (S1) and proposed system (S2 and S3).

Given	Number of acquired solutions		
Problem	(S1)	(S2)	(S3)
(P1)	1	1	5
(P2)	5	7	8

Table 2. Questionnaire result (1): Answer from the students in case of (P1).

		System		
	Questions	(S1)	(S2)	(S3)
1	Did the intragroup communication go smoothly?	2.7	2	2.7
2	Were you able to communicate with the teacher smoothly?	/	2	3.3
3	Were you able to solve the question in cooperation with the other students?	1.7	2	1.7
4	Is there any deadlock state during the session?	4	3.7	4
5	Is there any stagnant state during the session?	2.7	2.3	3

Table 3. Questionnaire result (2): Answer from the teacher in case of (P1).

	Questions	System	
		(S2)	(S3)
1	Were you able to communicate with the group smoothly?	3	4
2	Were you able to communicate with each student smoothly?	2	4
3	Were you able to instruct each student properly?	1	3
4	Was it easy to handle the group leaning as a teacher?	4	4
5	Is there any deadlock state during the session?	1	4
6	Is there any stagnant state during the session?	1	3

Table 4. Questionnaire result (3): Answer from the students in case of (P2).

	Questions	System		
		(S1)	(S2)	(S3)
1	Did the intragroup communication go smoothly?	2.3	3	2.7
2	Were you able to communicate with the teacher smoothly?	/	3	3.3
3	Were you able to solve the question in cooperation with the other students?	2.3	3.7	2
4	Is there any deadlock state during the session?	4	4	4
5	Is there any stagnant state during the session?	1.3	3.7	3.7

Table 5. Questionnaire result (4): Answer from the teacher in case of (P2).

	Questions	System	
		(S2)	(S3)
1	Were you able to communicate with the group smoothly?	4	4
2	Were you able to communicate with each student smoothly?	2	3
3	Were you able to instruct each student properly?	1	3
4	Was it easy to handle the group leaning as a teacher?	4	4
5	Is there any deadlock state during the session?	4	4
6	Is there any stagnant state during the session?	3	4

6.2 Evaluations about Achievement of Group Learning

At first, we quantitatively evaluate the achievement of group learning. As Table 1 indicates, for question (P1), five solutions can be found with (S3) which is the case when teacher changes SKF enabled and disabled, one solution can be found with (S2) when SKF is changed enabled and disabled according to the order of students and one solution can be found with (S1) when SKF is always enabled.

Also for question (P2), eight solutions can be found when teacher changes state of SKF, seven solutions can be found when students change state of SKF and five solutions can be found when no one changes the state of SKF.

These results shows that cooperative work is effectively proceeded by our proposed SKF and PKF switching control.

And also when PKF is controled by teacher makes better results than when it is controled by students. It is because teacher can monitor and comprehend total progress of cooperative work and change PKF enabled and disabled at the right time.

On the other hand, with a result of subjective evaluation by questionnaire, answer for "Were you able to solve the question in cooperation with the other students?" seems to indicate that control by student is better than the teacher. However, we analyzed update log of PKF and found that PKF was updated 20 times when teacher controlled SKF and was updated 16 times when student did. So the number of updating of PKF is more when teacher controlled the SKF than students did.

This indicates that few particular students study well by themselves and many other students only believe solutions of other students. Therefore, it can be said that achievement of group learning with SKF controlled by students is less effective than by teacher.

From the results of questionnaire for teacher, result for questionnaire of "Were you able to instruct each student properly?" was that controlling SKF by teacher was best. This is because switching SKF and PKF was performed well.

6.3 Evaluations about Communications

At first, evaluations from the view point of teacher are as follows. For questionnaire of "Were you able to communicate with the group smoothly?", we got a result that it was the best when SKF was controlled by teacher.

Reason of this result can be thought that teacher could give advice according to the progress of group learning. On the other hand, we got another result that writing to shared board with voice communication could make teacher easier to explain. This is because teacher can indicate true or false of student's answer by writing circle, which means true, on shared board directly. For questionnaire of "Were you able to communicate with each student smoothly?", we got a result again that it was the best when SKF was controlled by teacher. This is because teacher can write advices on individual PKF directly.

Secondly, evaluations from the view point of student are as follows. For questionnaire of "Did the intergroup communication go smoothly?", we got a result that it was the best when SKF was controlled by teacher. It seems that the reasn of thes result is when a student who can find a solution explains his/her approach and other students can discuss about it. Additionally, because they can see another student's approach and its procedure directly through SKF, shared board and voice chat seems to make progress of the study well. For questionnaire of "Were you able to communicate with the teacher smoothly?", we got a result that it was the best when SKF was controlled by the teacher. This result can be explained that teacher can give advice when students stick to the problem, and can give writing authority to another student who can solved the problem. This is because proposing a board of a student who has done well in finding the solution that works effectively.

6.4 Evaluations about Procedure of Group Learning

At first, evaluations about Procedure of Group Learning from the view point of teacher are as follows. For questionnaire of "Was it easy to handle the group learning as a teacher?", we got a result that it was the best when SKF was controlled by the teacher. This is because the teacher can monitor PKF and comprehend working progress of individual student. And also it may be effective that teacher and students can exchange opinions in group through PKF.

For questionnaire of "Is there any deadlock state during the session?", we got a result that there are no deadlock when the teacher control SKF. This is because teacher can give an advice in right timing when deadlock might occur. And also, we got same result from questionnaire of "Is there any stagnant state during the session?".

Secondly, evaluations from the view point of student are as follows. For questionnaire of "Is there any deadlock state during the session?", we got a result that there is no occasion of deadlock in all cases. On the other hand, for questionnaire of "Is there any stagnant state during the session?", we got a result that fewest stagnant occurred when a teacher control SKF. This result seems to be arisen because students can have been derived good solutions.

6.5 Overall Evaluations

From above mentioned results, overall evaluations of our method for domain of group learning are as follows.

(1) With the group learning support system, switching works SKF and PKF can activate communications among persons and accelerate communication among students and between a student and a teacher better when SKF is always provided. This result can be explained that students and the teacher can be able to concentrate to communication by giving them an explicit communication chance.

(2) When works SKF and PKF are switched, many solutions are derived compared to when SKF is always provided. This is because, when works SKF and PKF are switched during group learning, students can distinguish between self study time and group discussion time, and studying effect is improved.

(3) When works on SKF and PKF are switched under control of a teacher, many solutions are derived and stagnant state are not arisen compared to when they are under control of the students. This is because, for group learning, the teacher who manages total progress of studying can switch between works on SKF and PKF at right timing, then group learning can be carried out according to its progress of study. Therefore, studying effect is improved.

Additionally, it can be thought that our method can apply and produces an effect on any domains about intellectual cooperative works other than group learning. Our method may function well for domains where personal work and cooperative work are proceeded repeatedly, such as, cooperative design support for computer software.

On the other hand, this research indicated importance of control of information and knowledge flows between RS recognition and DS recognition. It is found that cooperative works in RS is improved qualitatively by not enhancing quantitatively but controlling information and knowledge flows between RS recognition and DS recognition according to the state of RS effectively, i.e. enabling and disabling the flows according to certain situations.

This is a new knowledge from a view point of effective applying method of symbiotic computing for intelligent cooperative works.

7. Conclusion

In this paper we propose a scheme to control availability of Shared Knowledge Field (SKF) in DS for cooperative works, according to the situation of tasks and workers in RS, in order to accelerate cooperative works. Using this scheme, advanced support to improve quality of intellectual cooperative works can be realized. In this paper, we applied our proposed scheme to group learning domain. From experiment results, we found that the cooperative problem solving by teacher and students were accelerated. Also we confirmed that the learning outcomes were improved, by controlling availability of the SKF, according to the progress of the group learning process. From these results we evaluated the effectiveness of our proposal.

In future work, we will tackle a scheme to automatically switching works between PKF and SKF which is performed manually in this system. Moreover we will investigate the possibility of this scheme to other application domains.

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