Collaborative Learning Agent for Promoting Group Interaction

Hee-Jeon Suh and Seung-Wook Lee

This project aims to design and develop a prototype for an agent that support online collaborative learning. Online collaborative learning, which has emerged as a new form of education in the knowledge-based society, is regarded as an effective method for improving practical and highly advanced problem-solving abilities. Collaborative learning involves complicated processes, such as organizing teams, setting common goals, performing tasks, and evaluating the outcome of team activities. Thus, a teacher may have difficulty promoting and evaluating the entire process of collaborative learning, and a system may need to be developed to support it. Therefore, to promote interaction among learners in the process of collaborative learning, this study designed an extensible collaborative learning agent (ECOLA) for an online learning environment.

Keywords: Online collaborative learning, monitoring agent, facilitator agent.

I. Introduction

With the rapid development of a knowledge-based society, it is of growing importance to create knowledge through collaboration with others beyond the individual. Recently, with the expansion of online collaborative and communication tools, online collaborative learning has become a new form of education in which learners create knowledge through interaction with other members [1], [2]. Moreover, online collaborative learning is regarded as an effective method for improving practical and highly advanced problem solving abilities and is being partly applied in the areas of action learning in companies, and of project-based learning and inquiry-based learning in schools [3], [4].

In contrast to individual learning methods, collaborative learning involves the complicated processes of organizing teams, setting common goals, performing common tasks, and evaluating the outcome of team activities. Also, collaborative learning needs the ability of self-directed learning, active interaction between groups, and satisfactory sharing of learning materials. However, teachers may have difficulty in monitoring all the collaborative activities and in helping learners in need. Moreover, existing individual-centered learning management systems (LMSs) have limitations in promoting and advising collaborative activities. Thus, our aim is to design and develop an extensible collaborative learning agent (ECOLA) that can be used to promote interaction among learners and to activate collaborative learning in an asynchronous text-based collaborative learning environment.

To design ECOLA, we studied models of online collaborative learning, analyzed factors and strategies of collaborative learning to enhance its presence and engagement, defined the roles of an agent that support online

asynchronous collaborative learning, defined computational models of group interaction, and built the ECOLA architecture complete with a monitoring agent, workplace database, and facilitator agent.

II. Related Works

1. Collaborative Learning

We examined collaborative learning models and strategies for the following reasons: to identify the collaborative behavior that should be recorded by the monitoring agent, and to define the procedure and factors of collaborative learning in order to derive strategies for generating advice.

A. Models and Processes of Collaborative Learning

Collaborative learning is a learning method in which a small group whose members have equal standing collaborate to attain common goals or to perform common tasks; through this process, they learn social and collaborative skills [4]. In successful collaborative learning, the active interaction of group members brings about high achievement, positive interdependency, and a strong sense of individual responsibility [4].

Although learners in online collaborative learning access the collaborative learning space from different remote places, they jointly perform tasks. They interact with one another, for instance, by using a collaborative workplace, as well as common learning resources and communication tools. The instructor and the facilitators support the group of learners by introducing collaborative learning tasks, by inducing the learners to perform the tasks, and by providing advice in the learning process.

We derived three types of online collaborative learning models: a general collaborative learning model, a collaborative discussion learning model, and a collaborative idea creation

Fig. 1. Online collaborative learning.

model. These models are based on our analysis of about ten face-to-face learning models, such as Jigsaw and Pro-Con, as well as various online learning activities, such as project-based learning, inquiry-based learning, and an online learning community. Moreover, we closely analyzed the behavioral elements of learners, as well as the support functions for the three types of collaborative learning models [5].

Table 1 shows the basic process of the general collaborative learning model. The process has five steps: building and arranging a team, developing learning goals and plans, individual learning, team learning, and sharing and evaluating learning outcomes [5].

B. Factors and Strategies for Successful Collaborative Learning

In some studies, collaborative learning generally includes the following factors: the size and composition of groups, the level of autonomy, the communication mode, the type and contents of interaction, and the interdependency and responsibility of group members [6]. According to these studies, the principal strategies for successful collaborative learning focus on group formation, group regulation, interaction, and structuring of the learning task [5], [6].

On the other hand, there are some considerations in online collaborative learning that differ from traditional face-to-face collaborative learning. First, in online collaborative learning, learners must direct their own learning; hence, they need self-directed learning abilities to manage their learning process [7]-[9]. Second, in computer-mediated communication, learners have difficulty communicating through bodily gestures and emotional expressions. This difficulty may hinder accurate and active communication in virtual space [10], [11]. Finally, in online collaborative learning, the intimacy and solidarity of group members is more important than in face-to-face communication [10], [11]. These considerations indicate that the effect of collaborative learning depends on the cognitive, social, and emotive domains.

We therefore examined various strategies that induce learners to do the following: to take the lead in their own learning process, to actively interact with others, and to pursue learning through cyberspace. These strategies pertain to a new field called 'cybergogy', which is a concept derived from the 'cyber' of cyberspace and the 'gogy' of pedagogy. Thus, it covers various strategies of teaching and learning in cyberspace. By promoting a cognitive, social, and emotional presence, cybergogy induces learners to be absorbed in learning [7]. Figure 2 configures the three elements of presence in online collaborative learning. These elements of presence were adapted from Garrison's cognitive, social, and teaching presence of a community of inquiry [8].
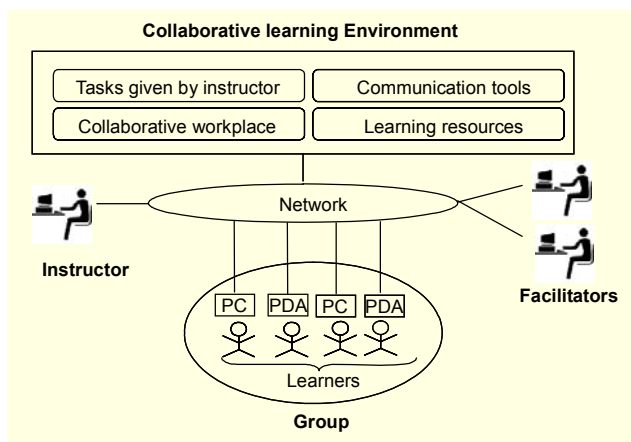
Table 1. Online collaborative learning process: a general model.

| Phase	Sub-processes	Collaborative tools
Building and arranging a team	• Identifying learning tasks, processes and methods • Identifying evaluation criteria and methods • Organizing teams for common goals • Dividing roles of members	• Project orientation • Team arrangement function
Developing learning goals and plans	• Identifying learning goals • Deciding on learning plans	• Discussion board • Schedule management
Individual learning	• Investigating individual tasks • Producing individual learning outcomes	• Personal notebook • Resource room • Searching tool
Team learning	• Sharing individual learning outcomes • Collecting, analyzing, and sharing information • Discussing issues and solving problems • Producing team outcomes	• Discussion board • Communication tools • White boards • Group resource room
Sharing and evaluating learning outcomes	• Sharing and giving feedback on learning outcomes among teams • Recording learning outcomes • Evaluating and reflecting CL processes and outcomes • Maintaining the learning community	• Assignment submission • Sharing tools • Communication tools • Evaluation checklist • Survey • Compensation
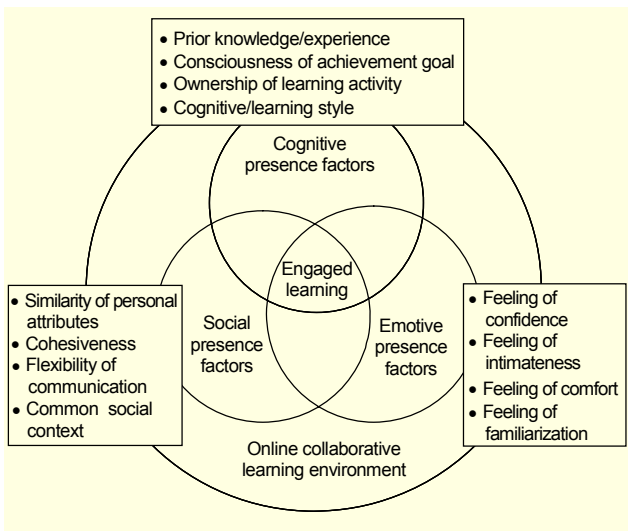
Fig. 2. Cybergogic model of collaborative learning.

Cognitive presence means the degree to which learners communicate with one another and construct meanings in the process of inquiry [9]. It also implies the use of activities such as questioning and criticizing, which are the main elements for critical thinking; moreover, cognitive presence is essential for higher-level thinking such as problem solving and the achievement of learning [7]. The factors of cognitive presence include prior knowledge and experience, a consciousness about the type and difficulty of achieving goals, the ownership of learning activities, and the cognitive or learning style.

Social presence means the degree to which learners are aware of interaction with others and sense interpersonal relations [10]. It enhances interaction in cyberspace, improves satisfaction, and promotes critical thinking whenever participants project individual characteristics upon the community [7]. A low level of social presence in the process of learning results in low interaction among participants. In turn, the low interaction may cause negative feelings of being isolated, lonely, and frustrated; it may also engender low motivation for learning. The factors of social presence include similarity of individual attributes, cohesiveness of the community, flexibility of communication, and a common social context.

Emotive presence means the degree to which learners are conscious of themselves and positively feel the surrounding environment through interaction with learning materials and with the participants of communication [10], [11]. Closely related to the level of interest, motivation, and expectation for activities, the emotive presence is expressed by personal emotions, feelings, beliefs, and values. Moreover, the factors of emotive presence include confidence, intimateness with the community, the comfort of the learning environment, and familiarity with the learning process.

One study examined how the social, cognitive, and emotive presence in cybergogy affects the learners' perceived learning achievement, satisfaction, and persistence. The results of that study show, first, that cognitive presence affects learning achievement, and, second, that the cognitive and emotive presence both affect the level of satisfaction and persistence with the learning process [12].

2. Collaborative Learning Agent

In the previous section, we discussed collaborative learning models and strategies that are effective in cyberspace. In this section, we examine the definition and roles of an agent in collaborative learning.

A. Definition of an Agent

In general, an agent is regarded as a function or software program that, when requested to do an action, understands the intention of the request and performs the action under the agent's own independent judgment [13]. Agents are characterized as follows: first, they autonomously function in relation to knowledge sharing without human intervention; second, they communicate with other agents; third, they recognize the environment and change appropriately in response to the environment; and, fourth, besides reacting to the environment, they evolve in accord with the ultimate goal.

In a learning situation, the autonomy of an agent means the ability to perform independently a task assigned to the agent by a person or other software. The autonomous feature of agents reduces users' burdens of learning activities, teaching activities, management activities, and so on [13]. It is impossible for educators to manage the large volume of information generated from learners' interaction. Agents can process a huge amount of data, make direct interventions in the process, and interact with other agents for carrying out tasks. Thus, they can help users concentrate on the contents that they are studying [14].

Furthermore, a human-like system developed using an intelligent agent makes users' interaction with computers even smoother [15]. Agents promote interaction between a human and computer for the delivery of information, and interaction among human users for high-level achievements. Another advantage of agents in education is that they provide a learning environment customized to individuals, a unified learning environment, integration between local and remote resources, and a mechanism for users to concentrate on knowledge provided by the agents [14].

Assuming that all agents in a distributed learning environment are grouped into three types, Lin and others [13] suggested personal agents, task agents, and regulatory agents. On the other hand, Jafari [15] suggested that, in order to extend the capacity of a learning system through intelligent agents, the learning system should be composed of agents performing teaching and learning for teachers and students. These agents are grouped into a digital technical assistant (plays the role of an assistant teacher who helps the teacher), digital tutor (provides help in response to specific learning needs, like a private teacher or a peer learner) and digital secretary (provides help in administrative and routine works). These agents will be conceptualized to perform specific tasks that have been performed by persons, and each agent will carry out its role focusing on a specific task.

Discussion on agents in the learning process began with intelligent tutoring systems for the learning of individuals. Recently there have been increasing discussions on agents playing the role of a facilitator that provides help from behind without showing itself to the learner [16], [17]. Such an approach enhances the understanding of the role of agents supporting collaborative learning and has implications for agent design.

In an intelligent tutoring system, agents act as guides or tutors, giving instruction to learners on what to do and leading them to perform tasks. Thus, these agents control the interface and continue to demand attention from learners [17]. In contrast, in an online collaborative learning environment, agents make no unnecessary interventions in the learning process; they merely monitor the process, collect data, perform statistical analysis, and provide information and advice to learners and teachers. Any intervention from these agents is minimized. Thus, learners can engage in collaborative learning without the feeling of being interrupted. In short, an agent is a software program that assists learning, promotes group work, and activates interaction and communication among participants [16], [17].

B. Roles of an Agent

Soller and others suggested three methods of supporting collaborative learning [18]. The first method involves quantifying the learners' joint work activities in a graph or other means and presenting the results to participating learners so that the learners can understand their collaborative acts. The second method involves monitoring and modeling all interactions among the learners and presenting differences between the ideal state and the current state. The third method involves analyzing the state of collaborative learning and providing advice for effective collaboration.

To explain the various roles of agents in the collaborative learning process, Hmelo-Silver focused on five steps [19]. The first step is to monitor the learners' progress, cooperation, participation, and so on, and to detect the difference of opinions. The second step is to induce activities according to the collaborative procedure for promoting group dynamics. The third step is to promote discussion by clarifying and presenting various topics. The fourth, which is used when collaboration comes to a standstill, is to intervene in the collaboration and to control the collaborative activities. The fifth step is to observe how the learners respond and to provide advice on correct actions.

Based on previous research, namely that of Soller and colleagues [18] and Hmelo-Silver [19], the common roles of agents that support collaborative learning are as follows: 1) monitoring the collaborative learning process; 2) giving

feedback and guidance to activate interaction and collaboration among participants; 3) giving information on the current state of a learner's interaction in the collaborative learning process; and 4) giving advice on the learning process according to the process and strategy of collaborative learning by comparing the current and ideal states.

Figure 3 presents the behaviors of an agent supporting online collaborative learning according to the process of general collaborative learning models. In each step, the agent should give advice on team arrangement and learning goals; it should monitor and give advice on the process of individual learning, as well as on team learning; and it should give feedback on performance, give information on results, and offer guidance on areas of study to follow up.
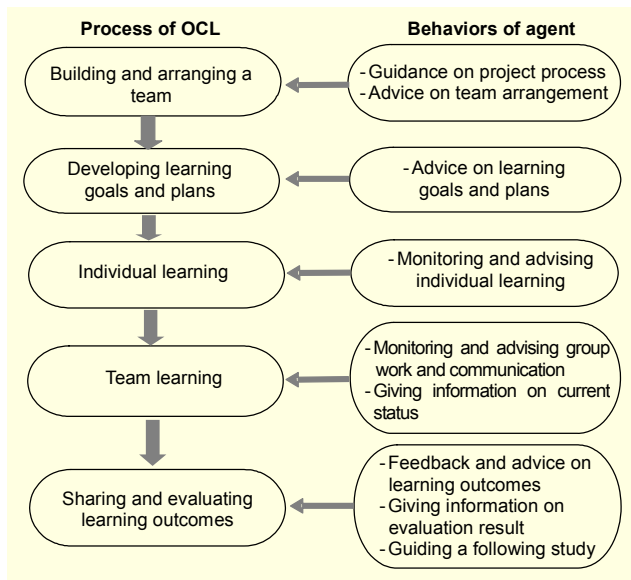
3. Computational Models of Group Interaction

Computational models of group interaction in collaborative learning provide functional computer-based representations that help us understand, explain, and predict patterns of group behavior [18]. On the basis of other research, we identified three computational models of group interaction: namely, the individual centrality model, the group cohesion model, and the dialogue analysis model. Moreover, we applied these three models for the facilitator agent of ECOLA, as shown in Table 4.

The individual centrality model represents the role and status of each member of the group. By using the centrality concept of a social network analysis, this model can automatically identify the roles and status of each member [20]-[22].

The group cohesion model represents group cohesiveness and group similarity through the density and centralization concepts of a social network analysis [21], [22].

Finally, the dialogue analysis model represents the group's cognitive processes on the basis of task-oriented interaction. This model uses a content analysis to help us understand and explain the process of group communication [23], [24].

A. Individual Centrality Model

Centrality indicates the degree to which a particular actor is positioned at the center of an entire network. That is, it highlights the importance or outstanding features of a single point in the entire network [20].

Degree centrality is a method of evaluating centrality on the basis of a learner's direct linkage to other learners. Degree centrality is presented by in-degree centrality and out-degree centrality. In-degree centrality means the degree of relations for learner A when learner A in a group receives messages from others in communicative situations (A←B). Learners with high in-degree centrality have more interactive activities and thereby receive more information or comments from others. They are popular learners or knowledge brokers in their community.

Out-degree centrality, on the other hand, means the degree of relations for learner A when learner A in a group sends messages toward others in communicative situations (A→B). Learners with high out-degree centrality are more active in providing information to others in discussion or providing comments on the opinions of others. They prefer to have open and friendly relations with many participants and have an important role of delivering information and data to their community [21], [22].

The formulas of degree centrality included in in-degree centrality and out-degree centrality are as follows:

$$d_i(M_i) = \frac{d_i}{(g-1)},$$
$$d_o(M_o) = \frac{d_o}{(g-1)}. \tag{1}$$

In (1), $d_i(M_i)$ is a participant's in-degree centrality, $d_o(M_o)$ is the participant's out-degree centrality, d_i is the sum of messages received by the participant from other participants, d_o is the sum of messages that the participant sends toward others, and g is the number of participants in the group.

In other words, we can obtain the degree centrality of participant M by dividing the number of participants connected to the actor by the total number of available participants. If there are g participants in the network, the total number of possible relations in the network is g - 1.

Figure 4 shows a graph of out-degree centrality.

In Fig. 4, learners s20, s18, s2, and s17 have higher out-degree centrality of interaction, and they are positioned toward

s1(f) 0.038
s24(m) 1
s4(m) 1
s23(m) 0
s3(f) 2
s5(f) 0
t4 1.714
s2(m) 2.786
s6(m) 1.071
s7(m) 0.179
s22(m) 1
s18(m) 4.071
s21(f) 0
s20(f) 5.143
s8(f) 0
t3 1.179
t2 2.107
t5 3.464
s17(f) 2.357
s12(f) 1.036
s9(f) 1
s19(f) 0
s16(m) 1
t1 1.036
s13(f) 1.036
s10(f) 0
s15(f) 0
s14(m) 1
s11(f) 0

s1-s24: learner, t1-t5: mentor, (f): female, (m): male
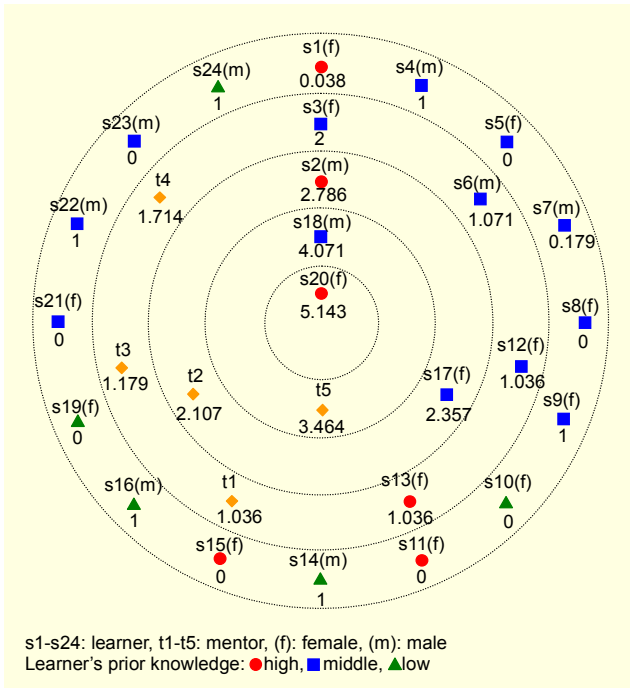Learner's prior knowledge: ●high, ■middle, ▲low

Fig. 4. Graph of out-degree centrality.

the center of the out-degree centrality circle. They actively participate and provide information and comments on the opinions of others. They also have friendly relations with many participants and have important roles in delivering information to their community. Furthermore, two mentors, t2 and t5, appear to have high out-degree centrality. They are connected with many learners and provide learners with guidance and information. The degree centrality graph also gives us information on each learner's other attributes, such as gender and level of prior knowledge [22].

B. Group Cohesion Model

The group cohesion model represents through density and centralization concepts of social network analysis [20]-[22].

Density

The cohesiveness of a network, which is referred to as density, is measured on the basis of inclusiveness and the degree of connection. To accurately calculate density, we must reflect two factors: namely, the scope of the group network and the number of participants linked to each participant [20].

Density has a value ranging between 0 and 1. When the density is 0, the network is without any connection; and when the density is 1, all the participants of a network are connected to one another.

In (2), the density is higher when v_k increases; v_k is the number of valued lines that express relations between participants in a network. If the relation between two participants has a specific direction, namely when the relation

A←B (learner A receives messages from others in communicative situations) differs from the relation A→B (learner A sends messages toward others in communicative situations), the maximum number of possible lines becomes $g(g-1)$.

To calculate the density, we use the concept of the average value. That is, we divide the sum of valued lines by the total number of possible lines in the network. Thus, density can be expressed as

$$Density = \frac{\sum_{k=1}^{n} v_k}{g(g-1)}. \quad (2)$$

Centralization

The concept of centralization differs from that of centrality. While centrality indicates the degree to which a participant is positioned at the center of a network, centralization refers to the centering tendency in the graph of the entire network. If the variance is 0, the actors are all homogenous and have no diversity. That is, the variance of degree centrality can be understood as an indicator of the level of homogeneity of the participants in a communication network [20]. Centralization can be used as the variance of degree centrality [20]. To obtain the variance of degree, we must find the mean of degree. The mean degree centrality is obtained by dividing the sum of the degrees of the participants on the network graph by the total number of participants.

We can express the mean in-degree, M_{di}, and the mean out-degree, M_{do}, as

$$M_{di} = \frac{\sum_{i=1}^{g} d_i(m_i)}{g} = \frac{L}{g},$$

$$M_{do} = \frac{\sum_{i=1}^{g} d_o(m_o)}{g} = \frac{L}{g}. \quad (3)$$

In (3), d_i is the in-degree, d_o is the out-degree, g is the total number of points, and L is the total number of lines in the network. To calculate the variance of degree on the other hand, we can use the means. Thus, we can express the variation of in-degree, S^2_{di}, and the variation of out-degree, S^2_{do}, as

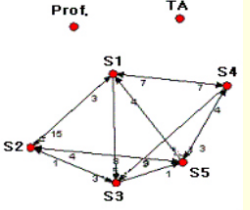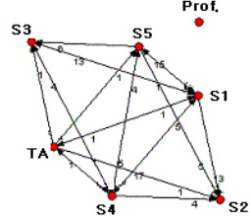$$S^2_{di} = \frac{\sum_{i=1}^{g} [d_i(m_i) - md_i]^2}{g},$$

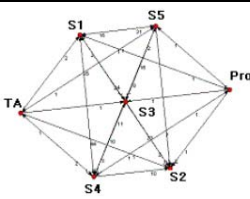$$S^2_{do} = \frac{\sum_{i=1}^{g} [d_o(m_o) - md_o]^2}{g}. \quad (4)$$

To analyze the path structure of the graph in Table 2, we used NetMiner 2.0, a tool for analyzing social networks [26]. The graph below presents the link relations among group members in the order of three group tasks. The graph shows that, as time goes on, the scope of linkage expands to professors and teaching assistants, and that the degree among learners intensifies.

The values of density and centralization in the graph below present the level of cohensiveness that results from group work.

In Table 2, the network density increases over time and the centralization approaches 0, suggesting that homogeneity increases gradually. That is, we can show the changes in group cohesiveness by calculating the density and centrality, and we can then analyze the learning process of the group.

Table 2. Example of an analysis of group cohensiveness.

Task	Group cohesiveness	
Task 1		Density 1.952 Centralization 0.642
Task 2		Density 2.524 Centralization 0.8
Task 3		Density 5.905 Centralization 0.352

S1 - S5: learners (group), Prof. : professor, TA: technical assistant

C. Dialogue Analysis Model

With the dialogue analysis model, we can investigate the frequency with which particular contents are discussed, and we can extract the patterns of interaction by diagramming relations between the contents and flow of the dialogue.

The dialogue analysis model was developed for identifying the behavioral patterns of group interaction in a collaborative idea-creation process. Table 3 shows seven categories of the dialogue analysis model. Each category has three to twelve subcategories [23], [24].

Table 3. Dialogue analysis model of group interaction.

Category (code)	Subcategory	
Understanding (U)	UA: answering UC: clarification UE: exemplify UH: analysis, compare UI: providing information UL: linking idea	UP: explanation UQ: questioning UR: retrieve prior knowledge and experience US: assumption UT: transfer, application UU: uncertainty
Argumentation (A)	AA: approval AC: conflict AO: opposition	AI: insistence AT: suggestion of a topic
Collaboration (C)	CA: advising CC: consent CH: helping	CI: integration CS: suggestion of idea
Maintenance (M)	MC: calling a peer MF: finding a focus MO: seeking an idea MP: opinion about project process	MQ: question about process MR: responding about process MS: summary of process MT: transition for next discussion
Evaluation (E)	EM: material evaluation EP: project-monitoring	ER: write a report ES: self-evaluation
Facilitation (F)	FA: checking roles of members FC: criticizing	FE: compliment FG: guidance
Socialization (S)	SG: greeting SH: joy, happy	SW: worry

Figure 5 shows the eight emergent interaction patterns extracted from the dialogue analysis model [24]:

1) Clarification pattern- learners clarify an idea and link ideas for solving a problem while giving information to each other.
2) Application pattern- learners apply an idea to different contexts and then synthesize new ideas.
3) Question and answer pattern- learners clearly build ideas through the interaction of questions and answers.
4) Integration pattern- learners understand a topic clearly and suggest their own opinions; they then integrate their different opinions into a unified idea.
5) Agreement pattern- learners agree with other learners' opinions or confirm a summary of their discussion.
6) Suggestion pattern- learners actively suggest their own ideas or opinions about a problem or unclear topic.
7) Conflict pattern- learners understand different levels of a topic and sometimes oppose the views of others.
8) Maintenance pattern- learners summarize the discussion or suggest various opinions about the progress of a project to
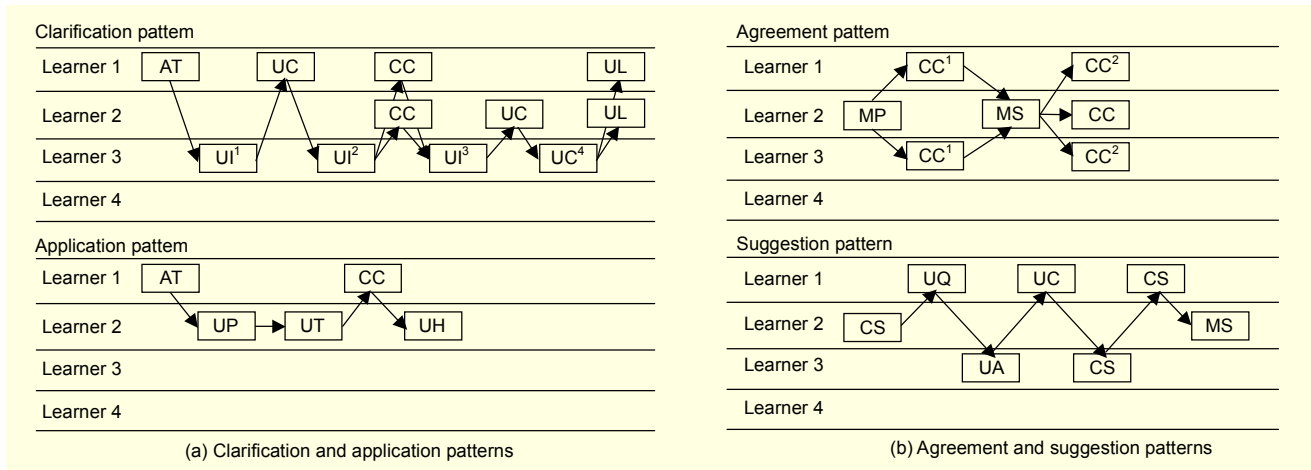
Fig. 5. Examples of patterns of the group interaction process.

facilitate the project's implementation.

III. Design and Implementation of ECOLA

1. Architecture of ECOLA

Figure 6 shows the structure and operating principle of an extensible collaborative learning agent (ECOLA). ECOLA has three main parts: the monitoring agent, which collects information on collaborative learning activities; the workplace database, which stores the monitored data; and the facilitator agent, which gives advice and sends alarm messages to promote participation. Moreover, ECOLA runs in connection with the learning management system (LMS).

The monitoring agent automatically gathers information on each learner's collaborative learning activities on the basis of the workplace reference model. By using this information, the facilitator agent then generates advice on collaborative learning and sends alarm messages to promote the participation of individual learners. Moreover, the facilitator agent statistically analyzes the collaborative learning process of individuals and teams.

The characteristics of ECOLA are as follows: First, it can run independently of the LMS; hence, it can be installed and operated in any type of LMS. Second, because it is included in the three representative models of online collaborative learning, namely, the general model, the discussion model, and the idea creation model, it is flexible and can be applied to various collaborative learning situations [5]. Third, because it can be used to analyze the current learning activities of each individual,
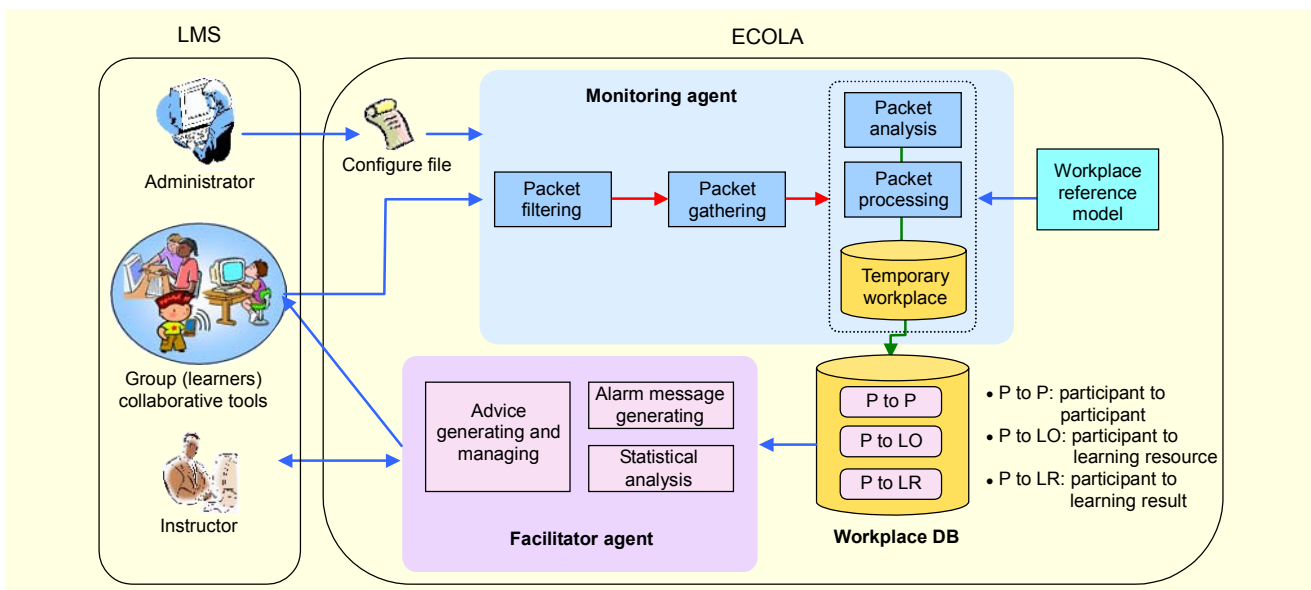

Fig. 6. Architecture of ECOLA.

it can customize various learning strategies for each individual.

2. Collaborative Learning Tools

Our collaborative learning environment for the LMS, in which agents run, is composed of communication tools, a task workplace, and learning resources. The communication tools include asynchronous communication tools and functions for checking the connection of team members and the status of the team process. The task workplace includes the following functions: task preparation, individual learning, team learning, and task evaluation. The learning resources, which include lecture contents and reading materials, are designed to produce research reports and team outcomes while each team executes project-based learning on a particular theme. In addition, to ensure that the collaborative learning environment could run in a multiplatform environment, we designed it to be used on a PDA as well as a PC.
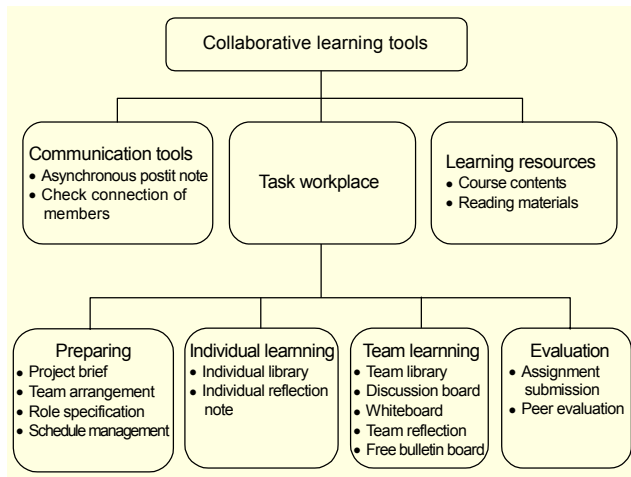

Fig. 7. Online collaborative learning tools.

3. Monitoring Agent

The monitoring agent collects, analyzes, and processes information on learners' collaborative learning activities and stores it in a workplace. In particular, the monitoring agent tracks the process of learners' collaborative activities according to the form defined by the workplace reference model and stores this information in a temporary workplace.

Figure 8 shows that the monitoring agent gathers the learners' data through packet filtering.

We divided the items of the workplace reference model into participant-to-participant (P to P) interaction, participant-to-learning resource (P to LO) interaction, and participant-to-learning result (P to LR) interaction. Table 4 shows these items in detail.

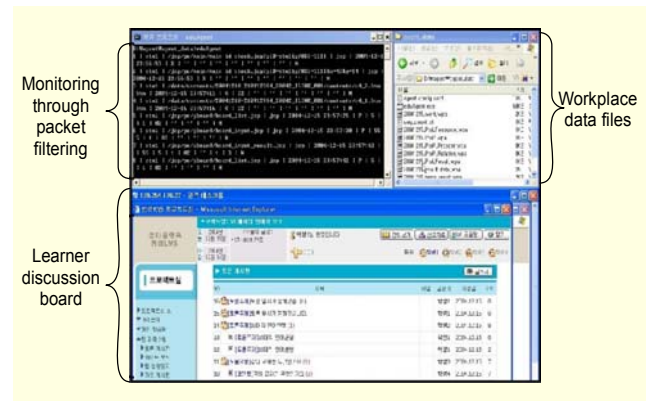The common items collected for the workplace reference

Fig. 8. Data gathering process of the monitoring agent.

Table 4. Workplace data structure.

Participant to participant interaction workplace	Participant to learning resource interaction workplace	Participant to learning result interaction workplace
Participant ID	Participant ID	Participant ID
Learning process ID	Learning process ID	Learning process ID
Learning object type	Learning object type	Learning object type
Process start time	Process start time	Process start time
Process end time	Process end time	Process end time
Project connection	Project code	Learning result info (Learning result ID, type, description)
Learner ID	Content code	
Learning present code		Bulletin board ID
Learning related code		Emoticon value
Project code		Message category info
Team code		Peer evaluation level
Bulletin board type		Outcome file
Message sender ID		
Message receiver ID		

model are as follows: basic information such as participants' ID, learning activity procedure, starting time, and ending time for all types of behavior of the participants.

a) The participant-to-participant (P to P) interaction workplace- information is collected on interaction between participants who simultaneously participate in the learning process in communicative situations or who send or receive messages. The P to P interaction workplace tracks the data from team learning tools like a discussion board and from the communication tools.

b) The participant-to-learning resource (P to LO) interaction workplace- information is collected on what and how long a learner studies with the aid of a particular learning resource.

c) The participant-to-learning result (P to LR) interaction workplace- all the results of a learner's activity are collected; for instance, the learner's opinion in discussion, the learner's final report on the given task, the emoticon value, the message

category information, and the peer evaluation level.

4. Workplace Database

We define the workplace as a space for storing information on current collaborative learning activities such as the learners' interaction, their use of learning resources, and their results. The information is stored in a fixed form on the workplace reference model and then utilized in the operation of the facilitator agent.

Figure 9 shows the workplace data for participant-to-participant interaction. The left side shows the participants' ID, the learning process ID, the type of learning object, the starting time of the process, the ending time of the process, the learning present code, the learning-related code, the project code, the team code, and the type of bulletin board.

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1. stu2|/jsp/pc/pboard/board_list.jsp|jsp|2005-01-17 19:24:00|"
   |20050117192400stu212LP|20050117192400stu212LR|5|1|02|"|"|"
2. stu1|/jsp/pc/pboard/board_list.jsp|jsp|2005-01-17 19:24:03|"
   |20050117192403stu113LP|20050117192403stu113LR|5|1|02|"|"|"
3. stu1|/jsp/pc/pboard/board_list.jsp|jsp|"|2005-01-17 19:24:10
   |20050117192410stu113LP|20050117192410stu113LR|5|1|02|"|"|"
4. stu1|/jsp/pc/pboard/board_view.jsp|jsp|2005-01-17 19:24:10|"
   |20050117192410stu114LP|20050117192410stu114LR|5|1|02|6|"|"
5. stu1|/jsp/pc/pboard/board_view.jsp|jsp|"|2005-01-17 19:24:15
   |20050117192415stu114LP|20050117192415stu114LR|5|1|02|6|"|"

Fig. 9. Example of participant-to-participant interaction workplace data.

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5. Facilitator Agent

The facilitator agent, which analyzes the data in the workplace database that was collected by the monitoring agent, automatically produces learning advice and alarm messages and statistically analyzes collaborative learning.

A. Generation of Collaborative Learning Advice

Figure 10 indicates the process of generating advice. The facilitator agent analyzes the information on current collaborative learning that was collected in real time by the monitoring agent, and then automatically produces advice. The rules of learning advice are formulated in advance by an education expert on the basis of collaborative learning models and presence factors. The facilitator agent uses the predefined rules to compare the current conditions of learners and, if the agent finds any gap, it generates appropriate advice automatically.

The facilitator agent decides to revise the contents of the advice. A human teacher can intervene in this decision process using the advice management tools. Then, the facilitator agent
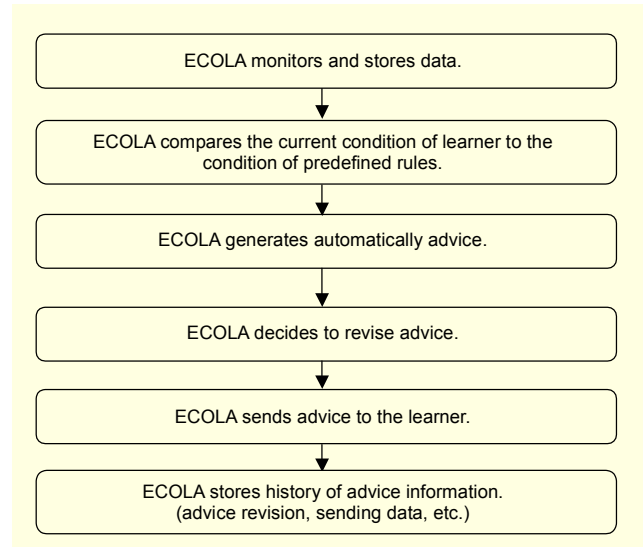

Fig. 10. Process of generating advice.

sends the advice to the learners, which the learners can see through the reflection board or e-mail. Last, the advice sent to learners is stored in a database of advice, along with the contents as modified and the date of transmission. This data can be used in the future to see the learning history of individual learners, to establish collaborative strategies, and to formulate rules for higher learning.

To enhance the engagement and learning effect in collaborative learning, we present six types of advice in line with the implemented factors of presence, as shown in Table 5.

For learners who lack prior knowledge, advice is generated by analyzing each individual learner's contents of learning, hours of learning, and time of learning; and this analysis is conducted with the aid of the workplace data of the participant-to-learning resource (P to LO) interaction. For learners who are passive in discussions, advice is generated by analyzing individual communication patterns on the basis of the individual centrality model; and this analysis is conducted with the aid of the workplace data of the participant-to-participant (P to P) interaction and the participant-to-learning result (P to LR) interaction.

B. Generation of Alarm Messages to Promote Participation

One of the facilitator agent's functions is to automatically generate alarm messages to induce learners to participate. Alarm messages are used to give learners immediate notice of recent replies or new messages on bulletin boards. The aim of the messages is to foster greater participation and to urge passive participants to collaborate more actively in the learning process.

The alarm messages are more social than instructional

Table 5. Type of advice and the parameters of related workplace data.

Type of advice		Workplace data parameter		Analysis content and method
Cognitive presence factors	Lack of prior knowledge	PtoLO_ participant ID PtoLO_ learning process ID PtoLO_ process start time	PtoLO_ process end time PtoLO_ project code PtoLO_ content code	Individual learning content and learning time
	Lack of individual reflection activity	PtoLR_ participant ID PtoLR_ learning process ID PtoLR_ learning object type	PtoLR_ learning result info PtoLR_ process start time PtoLR_ process end time	Frequency of individual reflection notes and time of writing
	Lack of discussion and collaborative knowledge creation	PtoP_ participant ID PtoP_ learning related code PtoP_ project code PtoP_ team code	PtoP_ learning object type PtoLR_ learning result info PtoLR_ bulletin board ID PtoLR_ message category info	Discussion message based on the dialogue analysis model
Social presence factors	Passive learner in discussion	PtoP_ participant ID PtoP_ learning present code PtoP_ learning related code PtoP_ process start time PtoP_ process end time	PtoP_ learning object type PtoLR_ learning result info PtoLR_ bulletin board ID	Individual communication patterns based on the individual centrality model
	Low-level group cohesiveness and interaction	PtoP_ participant ID PtoP_ learning present code PtoP_ learning related code PtoP_ project code PtoP_ team code	PtoP_ learning object type PtoLR_ learning result info	Group cohesiveness level based on the group cohesion model
Emotive presence factor	Low-level solidarity	PtoLR_ participant ID PtoLR_ learning result info PtoLR_ emoticon value	PtoP_ team code PtoP_ learning object type	Frequency and type of emoticon in the group

because they endeavor to induce participation and to encourage communication. Furthermore, in contrast to the learning advice, the alarm messages are presented directly to individual learners—not via the teacher.

The current alarm message function is a one-way, text-based form of communication. However, it should be developed into a two-way, emotive form of communication.

C. Statistical Analysis of Collaborative Learning

Other LMSs provide statistical results of individual learning, including test scores and the time of learning. However, they fail to provide a meaningful analysis on factors such as who actively participated in collaborative learning, whom the learners interacted with, and who mediated the interaction.

We defined the indicators of collaborative learning on the basis of collaborative learning models and strategies. As shown in Figure 11, the indicators include the frequency and timing of each learner's participation, the communication level and pattern, group interaction pattern, group cohesiveness, the type of discussion messages, and the emotional solidarity of the members.

From the statistical report, learners can see the current status of their individual and collaborative learning. Moreover, the
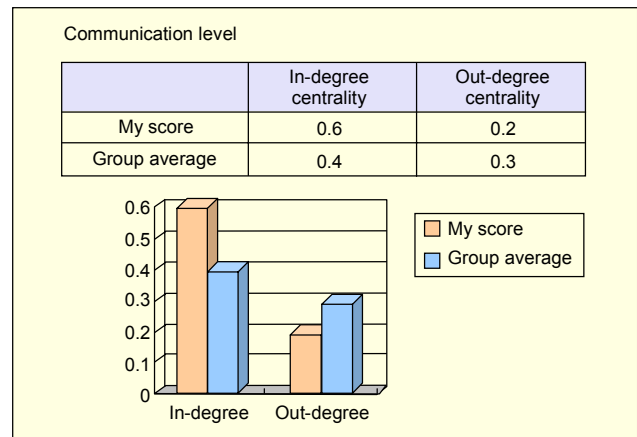

Fig. 11. A statistical report on the communication level.

teacher can glean information on the collaborative learning of individuals and groups in terms of social, cognitive, and emotive presence, and this information can be used to effectively promote collaborative learning.

6. Comparison of an ECOLA-Based LMS with other Computer-Supported Collaborative Learning Systems

To analyze the distinctive elements and superiority of

Table 6. Comparison the ECOLA-based LMS with other collaborative learning systems.

Items		ECOLA-based LMS	FLE	BSCW/TeamWave Workplace
Agent function	Monitoring and workplace database	• Monitoring the collaborative activities of learners • Building a database based on workplace reference model: P to P interaction, P to LO interaction, P to LR interaction	• Monitoring and building a database based on discussion: message category, number of postings, time of postings, response messages, depth of the discussion tree	• Limited gathering of interaction information: interaction event (generate, add, move, revise, read messages), peer information
	Facilitation	• Automatic generation of advice based on cognitive, social, emotive presence factors • Automatic generation of alarm messages • Statistical report on collaborative learning • The use of three computational models for analyzing group interaction	• Automatically generates advice on discussion participation • Automatically generates alarm messages about new postings • Statistical report on discussions	• Offers information on peer interaction
	Independence	• Independence from the LMS	• Dependence on the LMS	• Dependence on the LMS
Collaborative tools		• Group arrangement • Project management • Communication tools • Individual/team workplace • Evaluation, learning resources	• Discussion board on topics • Knowledge building • Sharing of learning outcomes	• Group arrangement • Discussion board • Individual notes • Whiteboard • Resource room

ECOLA, we compared an ECOLA-based LMS with existing computer supported collaborative learning (CSCL) systems. Table 6 shows the comparative results in relation to the following CSCL systems: flexible learning environment (FLE), basic support for cooperative work (BSCW), and TeamWave Workplace [27]-[29].

FLE is a CSCL system with agent functions [17]. The agent of FLE monitors learners' activities, provides learners with asynchronous advice, and gives information on connection. But the agent is limited in the process of discussion. Therefore, it cannot support entire collaborative processes from team building to outcome evaluation. Moreover, it can't be interoperable with other LMSs except FLE.

BSCW and TeamWave have many collaborative tools such as in Table 6. But both systems don't include any agent function and collect limited information about peer interaction events; for instance, generating, adding, moving, revising, and reading messages.

The learners in BSCW have a difficult time recognizing the state of peer interaction due to too many icons and objects presenting interaction information, and getting accurate information on peer interaction is also hard as such information is not updated automatically. On the other hand, TeamWave does not provide any historical record of learning for learners, nor does it analyze the information.

According to the results of comparison with existing CSCL systems, we found three distinct elements in which ECOLA is superior.

First, ECOLA automatically collects and analyzes information on three interaction types, participant-to-participant interaction, participant-to-learning resource, and participant-to-learning result interaction, of a learner's behavior in the entire collaborative learning process, in contrast to other systems, which collect information solely on the discussion process or the interaction events.

Second, ECOLA has an instructional strategy, cybergogy, and computational group interaction models, the individual centrality model, the group cohesion model, and the dialogue analysis model, for promoting learning and group interaction.

Third, ECOLA can run independently of the LMS, and it has interoperability in various types of LMSs.

IV. Conclusion

We designed and developed an agent that monitors collaborative learning processes and promotes the collaboration and interaction among students on-line instead of by human contact.

Most of the existing collaborative learning systems have the following problems. First, collaborative learning systems are typically composed of complex educational components. They operate dynamically, interacting and coordinating educational components including domain contents, individual and group information, interaction between instructor and students, group discussion, group evaluation, feedback, and so on [13], [15]. Second, they have no convenient assistance to manage the increasing demand for information and support extension of interaction. In collaborative learning systems, students can participate at any time and communicate with their instructors using communication tools such as e-mail, chatting software,

and bulletin boards. As a result, instructors may be spending more time and effort teaching in collaborative learning environments than in a classroom setting [13], [17].

We expect that the agent supporting collaborative learning helps overcome the problems of existing collaborative learning systems in part. Moreover, it may contribute to improve the achievement and satisfaction of collaborative learning.

ECOLA can be useful to coordinate educational components related to group work, because the monitoring agent automatically collects and analyzes information on learners' collaborative learning activities and then transforms it into meaningful information explaining the learning situation.

In addition, because the facilitator agent produces learning advice, offers alarm messages for promoting participation, and instead of a human teacher generates a statistical report analyzing collaborative learning of the individual and group, the facilitator agent can reduce the excessive workload of instructors in helping manage web-based collaborative learning.

Based on our results, we suggest the following areas of further research: First, additional intelligent elements should be considered. An intelligent agent for collaborative learning could help determine the opportune time or method of intervention in learning. It could also automatically formulate the rules of advice, and analyze discussions and conversations among learners [13], [14]. Second, we need to conduct a field test to verify the performance of the prototype agent and its effects on learning. In particular, we need to discern any problems that might arise in the monitoring agent and the facilitator agent [17]. Third, because we focused on the roles of the agent for asynchronous communication, we need to design and develop an agent for synchronous communication, particularly by using chatting and shared white boards [18]. Finally, given the future of the distributed learning environment, the application of an agent for collaborative learning should be explored in a multiplatform environment such as digital broadcasting, PDA's, and mobile phones [25].

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Hee-Jeon Suh received the BA degree in education from Yonsei University, Korea in 1991, and the MA and PhD degrees in educational technology from Ewha Women's University, Korea in 1994 and 2004. In 1994, she joined the Korea Educational Development Institute (KEDI). She has been in the Electronics and Telecommunications Research Institute (ETRI) since 2004, and she is now a Senior Researcher of development in personalized e-Learning systems based on mixed reality. Her research interests are in online collaborative learning systems, mixed reality based learning, and learner's cognitive-social presence.

Seung-Wook Lee received the BS degree in radio wave engineering from Hongik University in 1999, and the MS degree in information and communication from K-JIST in 2001. After his graduation, he joined ETRI. His major interests are in computer vision, mixed reality, and MPEG.