OPPORTUNISTIC GROUP FORMATION

- A THEORY FOR INTELLIGENT SUPPORT IN COLLABORATIVE LEARNING -

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ABSTRACT: *One of the major educational significance of the collaborative learning has is to enhance the participants' motivation to awaken mature reflection on their own understanding and externalize the result of it. Our interest here is to clearly grasp such educational significance of collaborative learning group. That is, how to characterize the organization of learning group, what functions the learning group has, in what situation a form of group is appropriate for, and so on. Based on the deep understanding of the property of the learning group, we try to build a model learning group formation. We call the model "Opportunistic Group Formation". The term opportunistic implies that the model can prescribe the right situation to form the leaning group. At ordinary situation, each learner is a series of tasks in individual learning environment. Once the opportunistic group formation model finds that the situation of a learner is the right timing to shift the learning mode from individual learning to the collaborative learning, the system taking charge of the learner proposes other systems to begin the negotiation for form the learning group formation. The negotiation is conducted by the negotiation process model which constitutes a part of the opportunistic group formation model. In this paper, among various issues on the negotiation process, we concentrate on the system of concepts to characterize the learning groups and the negotiation model for opportunistic group formation.*

1. INTRODUCTION

The fact that reflection and externalization of one's understanding are effective ways of learning has been widely accepted in the field of education . Thus, much effort has been devoted to the various research subjects related to the reflection and externalization [1]. Kashihara and his colleagues, for example, have developed an intelligent self-explanation support system, called SEA, and proved it had the desired effect. SEA guides learners toward better understanding by letting them to externalize their understanding as diagrammatic representation using well-designed graphical interface and by giving reasonable guidance on self-explanation process [2]. The theory on the motivation of learning also has close relation to reflection and externalization. Hirashima and his colleagues have developed a visual physics simulator with a function to lay emphasis on the flaw of learner's understanding and shown that the method szuccessfully gets learners to motivated to make reflection and externalization on their own understanding [3].

On the other hand, the pioneer study of CSCL (Computer Supported Collaborative learning) [4] also showed that interaction with computer learning companions can promote leaners' motivation in externa-lization /self-reflection process. Since then study on CSCL based on the educational principles closely related to the reflection and externalization, such as, "Learning by teaching" and "Learning by observing" has been attracting the interest of many researchers in these years. [5], [6], [7], [8], [9]. Needless to say, such principles have no special originality from viewpoint of practice of education. Group learning in a classroom, for example, is one of popular ways of education. The innovation originated in CSCL could be found mainly in rich communication aids with high-performance network technology and multimedia technology, or understanding support of collaborative learning based

on artificial intelligence technology. With these points as background, our interest here is to develop intelligent functions to support collaborative learning.

As we have seen, the major significance of the collaborative learning is enhancing the participants' motivation to awaken mature reflection on their own understanding and externalizing the result of it. However, the educational effect of collaborative learning largely depends on the context of learning. For a learner in the introductory phase of learning, for example, to give tutorials is more reasonable than to let him join the collaborative learning. Thus, the most important thing is to clarify the principle to conduct the collaborative learning, which includes the goals of collaborative learning, the categories to characterize the educational functions of a learning group, the rational organization of a learning group, the situations to initiate the learners into collaborative learning group, and so on. On the basis of the principle, a comprehensive educational model into which both individual learning and group learning are closely integrated. In our project, we have been aiming at building such an integrated model through a development of a framework, called FITS/CL, which provides learners with tutoring function in the ordinary mode of individual learning and encourages them to join collaborative learning in the right situation [10]. We call the integrated model "Opportunistic Group Formation." The term "opportunistic" implies that the model can prescribe the right situation to form the collaborative leaning group dynamically and context-dependently.

To embody "Opportunistic Group Formation", the key technology here is a negotiation mechanism among tutoring systems. Each system is responsible for a learner's learning process. When it finds the learner had better be engaged in collaborative learning, it initiates a negotiation with other tutoring systems to dynamically form a learning group appropriate to the learner's goal. The goal of negotiation is to obtain maximum social utility from collaborative learning. The inherent foundation to conduct the negotiation toward agreement is a shared value system to evaluate the quality of the learning group. The value system is also important part of the model of opportunistic group formation. It is divided into two categories, that is, self-centered value and social value. Therefore, the desired model of the negotiation should try to respect the self-centered opinions and reach in consonance among them from the view point of social value.

In this paper, among various issues on the model of "Opportunistic Group Formation", we will concentrate on the system of concepts to characterize the learning groups and the negotiation model for opportunistic group formation.

2. Opportunistic Group Formation

The idea of "Opportunistic Group Formation" can be expressed as follows:

Opportunistic Group Formation *is the function to form a collaborative learning group dynamically. When it detects the situation for a learner to shift from individual learning mode to collaborative learning mode, it forms a learning group each of whose members is assigned a reasonable learning goal and a social role which are consistent with the goal for the whole group.*

Here the roles assigned to learners are not assumed to be fixed during a collaborative learning session. When looking at the interaction process in detail, of course, we will find the role varies constantly. The role assigned to the learner should be somewhat abstract. That is, it roughly constrains the averaged behavior of the learners during the collaborative learning and allows the temporal variation.

In the following, we will briefly explain the outline of the opportunistic group formation and show an imaginary scenario of a collaborative learning session. Basically a learner is in the individual learning mode and studies under a tutoring function of FITS/CL. Once the system detects the desired situation for learners to switch into the collaborative learning mode based on the learner model, the system initiated negotiation process to form a learning group. At the same time, the system establishes a leaning goal and a desired role for the learner. This information is broadcasted to the other systems as a request for forming a collaborative learning group. The negotiation is conducted by only the systems which can appreciate the merits of collaborative learning. When the negotiation completed successfully, each participant in collaborative learning is well informed of the learning goal for a whole group and the role assigned to him/her. Then a new communication channel for the learning group is opened. (Although current implementation allows only textual information to go through the channel, it will be extended to voice communication channel in the future implementation). Learners can freely communicate with each other through the channel and the communication is not monitored by the systems in any sense. When the completion of the collaborative learning session is declared by one of the participants, the systems close the channel and ask the participants to evaluate their achievement. Each system updates the learner model based on the evaluation and encourages the learner under its charge to resume his/her learning task in the individual learning mode.

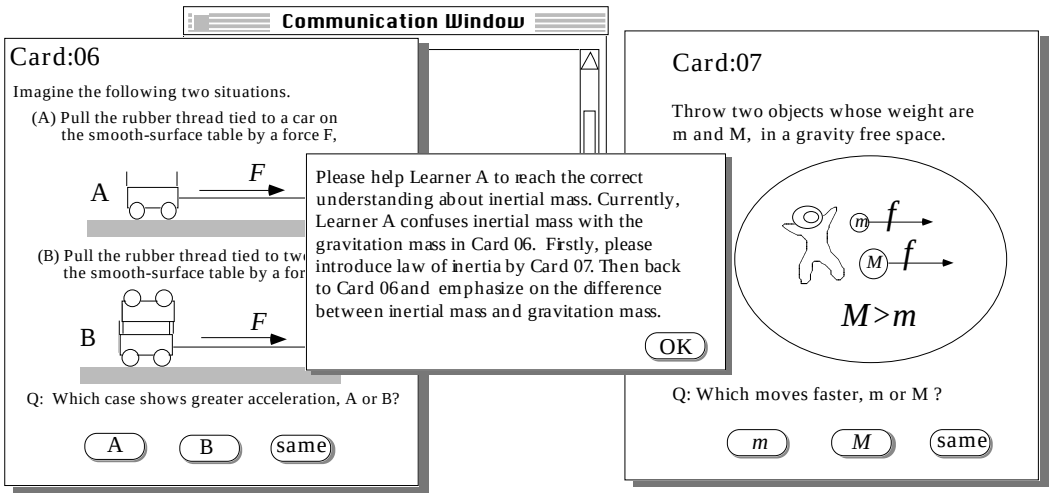


FIG. 1 AN ILLUSTRATIVE EXAMPLE OF A COLLABORATIVE LEARNING SESSION

TABLE 1 CONTENTS OF CARDS

No.	Contents of the card
01	An example of the law of gravity mass ($F=mg$)
02	Explaination of the law of gavity and gravity mass.
03	An example under the law of static friction ($F=\mu N$)
04	An example of mutual relation between static friction and gravity mass under the law of static friction
05	Explanation of mutual relation between static friction and gravity mass under the law of static friction
06	An experimentation of mutual relation between inertial mass and acceleration under the law of inertia ($F=ma$)
07	An experimentation on inertial mass focussing on differentiating it from gravity mass.

Hereafter, we use an illustrative example of a collaborative learning session shown in figure 1. The learning group in the example belongs to impasse-driven-LH type, which is one of the learning group types discussed later.

Teaching material is prepared as a set of hyper text cards. Table 1 shows the contents of the cards. Assume that learner A has already completed cards from no. 1 to no. 5 and learner B has completed cards from no. 1 to no. 7. The system S_B, which takes learner B under its charge, knows that the learner B clearly understands the difference between gravity mass and inertial mass. Imagine the learner A makes an incorrect answer, "the acceleration is same", to the question shown in card no. 6. Card no. 6 is appropriate for realizing the learning goal of "introduce-rule-by-example(law-of-inertia)" or "apply-rule-to-example(law-of-inertia). " The system S_A diagnose the cause of the learner A's impasse as confusion between gravity mass and inertial mass correctly. The system S_A establishes learner A's learning goal of breaking the impasse. Based on the diagnosis and the goal, S_A searches for the card which refers only the law-of-inertia to let learner A concentrate on it, because the A's mistake is caused by the misapplication of the law-of-gravity. S_A selects card no. 7 which is apparently designed to differentiate the inertial mass from the gravity mass. Then S_A judges whether the learning mode should be switched from the individual learning to the collaborative learning. The judgment is formed on the basis of the importance of the impasse, learners aptitude to collaborative learning, history of learning, and so on. Assume that learner A needs more experience of collaboration and the impasse is quite important to reach deep understanding of the law of inertia. In such a case, system S_A decides to switch learner A's learning mode to collaborative learning and submits a request for forming a learning group. The request message includes the learning goal and the desired role (Learner) of learner A.

When System S_B receives the request, it judges whether learner B can expect any benefits from the collaborative learning. Because learner B has already completed card no. 6 but not experienced the important impasse, S_B gives an affirmative answer to S_A's request. The reply message includes the learner B's goal of "to reach deep understanding by externalizing his/her own understanding" and the desired role (*Helper*). Of course, other systems are also expected to reply to the request but the reply is not necessarily affirmative. The negotiation is conducted by all the systems which give an affirmative to the request. The goal of negotiation is to assign reasonable role to all the members, for example, a *Helper*, a *Learner*, an *Observer* and so on. In section 4, we will see the detail of the negotiation process.

TABLE 2. TRIGGERS FOR OPPORTUNISTIC GROUP FORMATION

Trigger	Explanation
Impasse	When a learner has some difficulty on a learning process, the imasse trigger is detected. If the trigger is worth to initiate colloborative learning, the system detected it submits a request to public.
Review	When a learner completes the given task, the review trigger is detected. If review of the task is worth to be carried out as a collaborative activity, the request for group formation is submitted to public.
Program	This trigger is prescribed by teaching material authors in advance. For example. the author may prescribe the necessity of group learning by an experiment for a topic. In such a case, the program trigger will be detected when a certain number of learnes successfully acquire prerequisite knowledge for the experiment.

In figure 1, we adopt rather simple scenario in which the learning group consists of only two learners, that is, A as a *Learner* and B as a *Helper* . Figure 1 shows the snapshot of the interface for the learner B in initial phase. The dialog in the frontmost gives leaner B the explanation of learner A's impasse and the learning goal established for learner A. And then the communication channel is opened for them. Systems S_A and S_B wait until the learners achieve the goal and push the "quit" button.

3. A MECHANISM FOR LEARNING GROUP FORMATION

The transition from individual learning to collaborative learning is arranged by the negotiation opened by a request from a system. We call an event, which is taken place in the individual system and caused the request, as a trigger. The trigger can be regarded as necessary condition for the transition. And it depends on the result of the negotiation whether the transition should be made or not. We can say the systems participating the negotiation do a form of distributed decision making. The inherent foundation to conduct the negotiation toward the agreement is the shared understanding of the collaborative learning. In this section, among various issues on the shared understanding, we will concentrate on the types of triggers and the rational organization of collaborative learning groups.

3.1 Types of Triggers for Collaborative Learning

Trigger can be defined from two viewpoints. From individual system's viewpoint, it specifies the right timing for the learner to be able to expect great benefit from the collaborative learning. From viewpoint of a whole learning group, on the other hand, it affords a valuable opportunity for collaborative learning.

The major goal of collaboration , needless to say, should be to achieve the goal of the learner who pulled the trigger. When the collaboration is triggered off by a learner's impasse, the major goal of the learning group is to break the impasse and guide him to reach the correct understanding. At the same time, other participants might be able to expect some benefit from the collaborative learning. The benefits largely depends on the value of the trigger. For example, if a learner's impasse is a key to reach deep understanding and cannot be experienced very often, the trigger pulled by him/her may provide other learners with invaluable resource for learning. In this sense, the detection of the trigger is very important part of opportunistic group formation. Three types of triggers in our model are summarized in table 2.

Such triggers are detected by a set of simple rules whose precondition specified in terms of a learner model and teaching material knowledge. However, the process for decision making from the trigger detection to the request submission is rather complex and is affected by a comprehensive knowledge such that a learning goal, teaching strategies, a model of collaborative learning group and so on. In the following, we will briefly explain the outline of the process.

When the system which detects a trigger decides to move into collaboration learning mode, it assembles the request message to send. The message protocol we have adopted is originally based on KQML protocol [11],[12] but specialized in the negotiation of our interest. The initial request message includes the learning goal for the learner, the desired role, the desired learning strategy, justification for the request and so on. The learning goal concretely specifies the expected effect of learning, for example, the goal for learner A in figure 1 is to resolve the impasse of a learning process of "to learn the difference between gravity mass and inertial mass in card no. 6." And the learning strategies specifies the way to accomplish the learning goal, for example, either inductive way of learning or deductive way of learning. Justification explains why the system tries to form a collaborative learning group based on teaching material knowledge, learner's model, learning history, and so on. Such information provides a reasonable ground for the negotiation, that is, the participants can verify the rationality of the other systems' request based on the information. Opening the justification to public enables the negotiators to share the common belief space in some extent.

TABLE 3. ROLES OF COLLABORATIVE LEARNING PARTICIPANTS

Role	Learning-goal / Behavior
Learner	ALearner acquires knowledge to dissolve the impasse from Helpers.
Helper	A Helper mainly helps a learner to attain his / her goal. The learning goal of the helper is to gain the educational benefit of "learning by teaching."
Active-Helper	An Active-Helper is-a Helper who actively helps Learners.
Passive-Helper	A Passive-Helper is-a Helper who indirectly hepls Learner supporing the Active-Helper.
Mediative-Helper	A Mediative-Helper mediates collaborative activity of learning group. The major learning goal is to gain the educational benefit of "reflection".
Presentator	A Presentator performs his / her own understanding of a topic. The learning goal of the presentation is to gain the educational benefit of "reflection."
Observer	An observer learns from collaborative activity of other learners. The learning goal of the observer is to gain the educational benefit of "learning by observing"
Supervising-Observer	A supervising-observer is-a Observer and observes collaborative activity of other learners and evaluates it.
Participant	A participant gives some comments observing collaborative activity of other learners. The learning-goal of the participant is to promote his own understanding.
Debater	A debater discusses with other learners who have different level of understanding of the topic. The learning-goal of the debater is to gain the educational benefit of "learning by discussion".

3.2 Typology of Collaborative Learning Group

The possible roles that a learner would play in a collaborative learning are summarized in table 3. This is another important part of our model to characterize the essential features of a learning group. The key to the characterization is to attach importance to the interaction among the members of a learning group. For example, impasse-driven-LH learning group, we have seen in section 2, the *Helper* can expect the educational benefit of "learning by teaching" from the interaction with the *Learner*, while the *Learner* can expect "learning efficiency. "

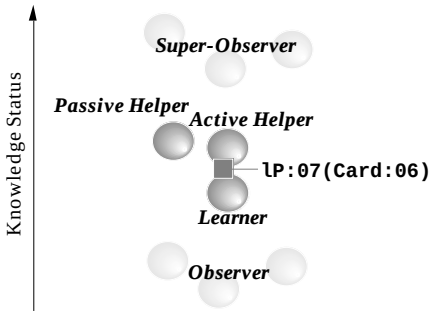


FIGURE 2 CONFIGURATION OF IMPASSE-DRIVEN-LH-RAPID-ACHIEVEMENT

In the following, let us consider the typology of collaborative learning according to the organizational features of a learning group. The typology is based on the types of triggers and the desired feature of interaction. The typical classes of learning groups in our model of opportunistic group formation are shown below.

Impasse-driven LH type of learning group

Possible roles of members: *Learner*, *Helper*, *Observer, Participant*

Typical organization: The learner who has an impasse is allotted *Learner* and the learners who can break the impasse is allotted *Helper*. *Observer* is allotted to learners who are not good at the topic related to the impasse. The learners who already experienced the impasse may act as *Participant*. This allotment aims at confining the topic of conversation to those which contribute to overcoming the impasse. This type could be more specialized in goal-oriented organization. Figure 2 illustrates Impasse-driven LH rapid-achievement type, in which *Helper* is restrictively allotted to the learners of great apt. In figure 2, the distance between learners mimetically represents the strength of the expected interaction between them. The vertical axis designates the knowledge status of each learner. For example, we can find a *Supervising-observer* knows most about the topic and is in weak interaction with a *Helper*.

Review-driven Panel type of learning group

Possible-role of members: P*resentator, Participant, Observer*

Typical organization: The leaner caused a review trigger explains his own solution/understanding of the topic as *Presentator*. *Participants* are expected to give some comment on the presentation and ask some questions.

Program-driven Discussion type of learning group

Possible-roles of members: *Participant, Observer*

Typical organization: The learners who are allotted *Participant* has similar level of understanding of the topic. They are expected to arrive at a better understanding through frank discussions about the topic. In principle, at least one of *Participants* should be good at the topic to keep the soundness of the discussion.

4. Negotiation Process

As mentioned above, the request sent by a system represents its personal needs to let the learner engaged in collaborative learning. On the other hand, it is also important to maximize the benefit of a whole group taking benefit of each member into consideration. Thus, the main purpose of the negotiation is coordinating between personal needs of each learner and benefit of a whole group.

The negotiation process is roughly divided into two stage, that is, *information gathering stage* and *negotiation stage*. In the information gathering stage, from request submission until all the systems replay to the request, the systems tend to be somewhat personal, because the decision making largely depends on characteristic of detected triggers and the local information about the learner in its charge.

When a system S_B receives the request from another system S_A, S_B judges whether it is acceptable based on learner model and sends the judgment in reply to the request. When system S_A receives the reply messages from all the systems expected to reply, it declares the opening of negotiation.

In this negotiation stage, the type of collaborative learning group, the role of each learner and the topic to be discussed, are decided. In our model of opportunistic group formation, negotiation process model and message protocols play an important role to loosely coordinate the negotiation process so as to reach a reasonable settlement. The negotiation process model broadly prescribe negotiation process in the form of transition network. Each system has its own negotiation process model and conduct the negotiation based on it. Message protocols prescribe the basic meaning of messages together with negotiation process model. That is, the events of message submission and receipt are attached to the directed links in the negotiation model, and works as the status transition condition.

Thus, we could say that the model and the protocol works as the first principle to conduct the negotiation for opportunistic group formation. Intuitively speaking, for instance, *give-opinion* messages frequently appear in the early phase, and a *submit-alternative-proposal* message in the later phase. The negotiation process model encourages each system to express personal opinion in the early phases, and work out compromise opinion in the later phases.

The negotiation process model also leads the internal decision making of each system from viewpoint of group-wide benefit. The leading is realized by adjustment mechanism of priority of decision making criteria. The criteria could be classified from two different viewpoint. The first one is personal/group-wide viewpoint. As we have discussed, in general, the decision on collaborative learning is hopefully made taking both the personal criteria and group-wide criteria into consideration. The personal decision is done based on the criteria from personal viewpoint which gives much importance to maximizing the benefit for each learner, referring the internal information on each learner's status. The public decision is done based on public decision criteria so as to maximize the benefits of a whole group, referring all the information presented to the public.

The other one is absolute/preference viewpoint. The absolute criteria is necessary condition which any learning groups must meet. On the other hand, the preference could be partially neglected according to the priority attached to the fragments of the criteria. The priority also could be arranged dynamically to cope with the situation.

In the early stage of the negotiation, the most of the decisions, made by each system are based on only the personal criteria. The major reason why is lack of public information. Therefore, conflict of benefits could be easily happen. The conflict, however, is essential because it encourages each system to open the personal stance and local information to public. As more local information are presented to public through the negotiation process, the sufficient environment to make a decision based on group-wide criteria is gradually created. In later phase, the negotiation model makes group-wide criteria stronger than in early phase.

4.1 A Model of Negotiation Process

Negotiation among systems is too complex to reach the agreement when leaving them to take their own courses. From the viewpoint of prompt settlement of the negotiation, a centralized control negotiation model, that is, mediation by a single agent, seems to a good solution of the problem. It is questionable, however, whether such a mediator can catch the real needs of every negotiators of learning group formation.

The fair mediation is possible, only when the mediator obtains enough information about all the learners. Moreover, it should have the capability to revise the proposals so as to achieve a compromise when there exist alternative proposals. It is quite difficult task for a single mediator which has only partial information about the learners. Taking consideration of the facts that each negotiator can have more information than a single mediative system in principle, the separation of mediative function does not make sense.

Based on above observation, we adopt fairly distributed decision making scheme in the model of opportunistic group formation. In the scheme, each system constantly updates it own belief about the status of negotiation process and actively participates in it switching appropriately back and forth between the personal view and the group-wide view.

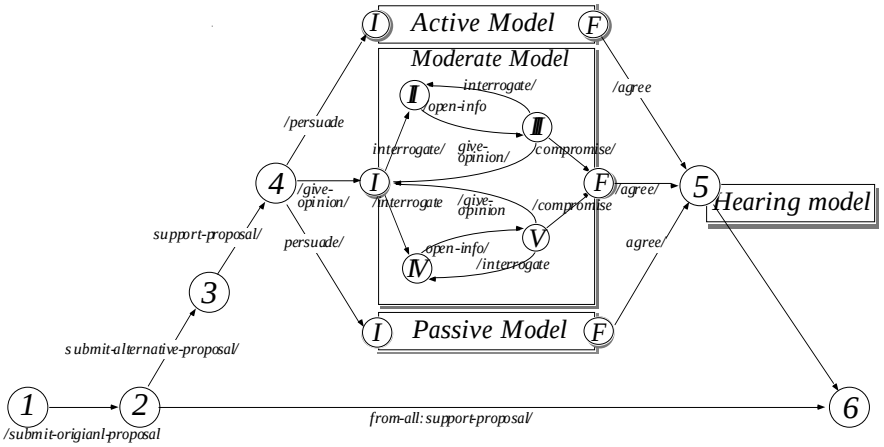
The major part of this scheme is represented as a *negotiation process model*. It is integrated into each system and controls its behavior in negotiation. Figure 3 shows two types of the negotiation process models, that is, one is for *proposers* as shown in figure 3 (a) and the other is for other participants in (b). The *Proposers* who submit at least one proposal act as the negotiators representing all the supporters of her opinion.

In the negotiation process model, nodes represent a status of a system and directed links represent the state transitions. Condition of the transition is attached to the link in the form of X/ or /X, where X/ (/X) means that the system receives (submits) a message whose performative is X. Note that the model prescribes the negotiation process in terms of performatives without referring the contents of messages. The nodes of model prescribe the behavior of the system to cope with the situation. Performatives in our model. are basically originated from KQML but specialized for opportunistic group formation.

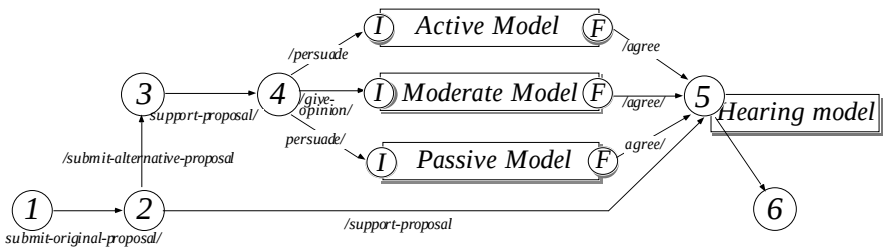
4.2 Overview of Negotiation Mechanism

Let us assume that system S_A submits an initial request for collaborative learning. When other systems receive the request, each of them replies either in the affirmative or in the negative. In the case of the affirmative, the system, say S_B, opens the basic necessity information about learner B in its charge to the public. We could say the aggregation of information about the learners creates mutual understanding among the systems participating to the negotiation. we call the first stage from the request submission until all the systems reply to the request as the information gathering phase.

After the information gathering phase completed, the negotiation phase is open. S_A tries to devise its own proposal, which is especially important to clarify the goal of a whole group. Following the negotiation model M_X shown in figure 3(a), S_A submits the proposal message P_A whose performative is *submit-original-proposal* and makes the transition from node $n_{X,1}$ to $n_{X,2}$, where $n_{X,i}$ represents the i-th node of M_X. In $n_{X,2}$, S_A waits for the evaluation of the proposal from other systems. The other systems which does not have any proposal follows the negotiation model M_Y shown in figure 3(b). Once they receive the proposal message from S_A, they make the transition from node $n_{Y,1}$ to node $n_{Y,2}$ and evaluate the proposal. If the proposal cannot be acceptable for a system, it tries to devise the alternative



(A) NEGOTIATION MODEL FOR A PROPOSER: M_X



(B) NEGOTIATION MODEL FOR PARTICIPANTS: M_Y

FIGURE 3 NEGOTIATION PROCESS MODELS

proposal and submit the proposal message P_B whose performative is *submit-alternative-proposal* and makes the transition from node $n_{Y,2}$ to $n_{Y,3}$. In case that proposal P_A can be acceptable for a system, it submits the supportive message whose performative is *support-proposal* and shifts its status from $n_{Y,2}$ to $n_{Y,5}$. The system in such a situation is called a *supporter* for P_A, while one in either $n_{X,3}$ or $n_{Y,3}$ is called a *negotiator*, who represents the supporters for its proposal.

Assume that S_A and S_B are in $n_{X,3}$ and $n_{Y,3}$ respectively. S_A (S_B) makes transition from node $n_{X,3}$ ($n_{Y,3}$) to node $n_{X,4}$ ($n_{Y,4}$), when the rest express the supportive messages for either P_A or P_B. The systems in $n_{X,4}$ or $n_{Y,4}$ are just ready for starting the negotiation among them.

S_A and S_B follow one of three different models represented as boxes in figure 3, that is, an active model, a moderate model, and a passive model. The system with the active model tries persuasion on the systems which announced different proposals. On the other hand, the system with the passive model works out a compromise proposal. In principle, the active model is reasonable at the early stage of negotiation because gathering personal justifications is essential to create the foundation of negotiation. When the situation is still in a draw after a while, all the negotiators replace the models with the moderate ones. Moreover, in case of difficult negotiation, the negotiators with less supporters should replace the model with moderate or passive one. When a system agreed with others as a result of the negotiation, it makes transition to $n_{X,5}$ or $n_{Y,5}$. The nodes $n_{X,5}$ and $n_{Y,5}$. represent the status in which the system agreed with other systems' proposals. The nodes are expanded into a submodel, called hearing model. The hearing model designed so as to produce the behavior of an attentive hearing, that is, it constantly express its opinions on proposals discussed.

When all the systems are in the hearing mode, the negotiation has been completed successfully.

5. Conclusion

In this paper, we have discussed a model of opportunistic group formation. The negotiation is conducted by the negotiation process model which constitutes a part of the opportunistic group formation model. In this paper, among various issues on the negotiation process, we concentrated on the system of concepts to characterize the learning groups and the negotiation model for opportunistic group formation.

The example of negotiation process shown in the previous section makes it clear that key to the successful negotiation is how to conceptualize the content of the communication, the negotiation process, and the communication protocol and so on. So, the importance of ontological issues for CSCL system design [10] cannot be overemphasized. What should be notice is to find a good ontology to represent details of the model of opportunistic group formation from the educational point of view. We have been currently engaged with the issue.

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