How Can We Form Effective Collaborative Learning Groups?

— Theoretical justification of "Opportunistic Group Formation" with ontological engineering —

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Abstract. Our research objectives include constructing a collaborative learning support system that detects appropriate situation for a learner to join in a collaborative learning session, and forms a collaborative learning group appropriate for the situation dynamically. In this paper, we describe a system of concepts concerning learning goals expected to attain by learners through collaborative learning process with justification by the learning theories. With the ontology, it will be possible to compare and synthesize the learning theories to design the collaborative learning settings.

1 Introduction

Many researchers on educational technology have extended the field of study from stand-alone learning environment to group collaborative learning environment. Although advantages of collaborative learning over individual learning are well known, the collaborative learning is not always effective for a learner. Educational benefit that a learner gets through the collaborative learning process depends mainly on interaction among learners. The interaction is partly influenced by relations among members of learning group, which suggests that how to form an effective group for the collaborative learning is critical to ensure educational benefit to the members.

Our research objectives include constructing a collaborative learning support system that detects appropriate situation for a learner to join in a collaborative learning session, and forms a collaborative learning group appropriate for the situation dynamically. To fulfill these objectives, we have to consider the following:

1. How to detect the appropriate situation to start a collaborative learning session and to set up the learning goal,
2. How to form an effective group which ensures educational benefits to the members of the group, and
3. How to facilitate desired interaction among learners in the learning group.

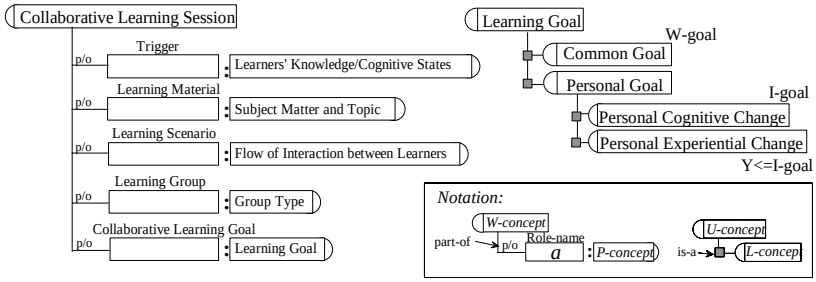

Fig. 1. Collaborative Learning Ontology

We have discussed item 1 in our previous papers[11, 12], and this paper focuses on item 2. When we have clarified item 2 and extracted the desired interaction in the group, we would consider item 3.

There are many theories to support the advantage of collaborative learning. For instance, Observational learning[2], Constructivism[18], Self-regulated learning[10], Situated learning[15], Cognitive apprenticeship[6], Distributed cognition[20], Cognitive flexibility theory[21, 22], Sociocultural Theory[24, 25], Zone of proximal development[24, 25], and so on. If we select a theory from these and form a learning group based on the theory, we can expect effective collaborative learning with the strong support of the theory. However, it is difficult to understand all theories because these theories are derived from a wide research area including pedagogy, sociology and psychology. Moreover, we can expect different educational benefits based on these learning theories, and observe various kinds of interaction between learners through collaborative learning process. Due to the diversity, it is difficult to list the learning theories effective to gain a specific educational benefit for a learner, and to compare the theories to form a suitable collaborative learning group for the learner.

Therefore, we have been constructing a system of concepts to represent collaborative learning sessions mentioned in these learning theories[12, 23]. We call the system of concepts "Collaborative Learning Ontology". In this paper, we focus on "Learning Goal Ontology" which is a part of the Collaborative Learning Ontology. The concept "Learning Goal" is one of the most important concepts for forming a learning group because each learner joins in a collaborative learning session to attain a learning goal. The Ontology will be able to make it easier to form an effective learning setting and to analyze the educational functions of a learning group.[16, 17]

2 Structure of Collaborative Learning Ontology

There are many factors to characterize a collaborative learning session. When should the learners start a collaborative learning session? What subject matter should they learn in the session? How should the session progress? Who should join in the session? What educational benefit should be expected for each learner through the session?

We picked up concepts to represent a collaborative learning session through a survey of learning theories and studies on collaborative learning. As a result, we set up five primitive concepts to characterize the session: trigger, learning material, learning scenario, learning group, and learning goal. Fig. 1 shows the conceptual structure of collaborative learning ontology.[1] The concept "trigger" means the desired situation for each learner to start a collaborative learning session. The concept "learning material" means the subject matter, learning topics, and problems to be addressed in the session. The concept "learning scenario" means how the collaborative learning session progresses; for example, a learner demonstrates how to solve a problem and another learner observes it, and then they exchange their roles. The concept "learning group" means a group type and each learner's role in the session. Here, we focus on the concept "learning goal". The concept "learning goal" can be specified as two kinds of goals: "common goal" as a whole group and "personal goal" for each learner. The concept "personal goal" can be specified as two kinds: the goal represented as a change of a learner's knowledge/ cognitive states, and the goal attained by interaction with other learners.

3 Learning Goal Ontology

As Fig. 1 shows, the collaborative learning ontology has three kinds of goals: one common goal and two kinds of each member's personal goals. In this section, we distinguish among the three goals and identify the goals with justification based on learning theories.

3.1 Classification of Goals for Collaborative Learning

A learner will join in a collaborative learning session to attain learning goals. We classify the goal of the first person (I), that of the first person to interact with the second person (You), and that of the whole group as I-goal, Y⇐I-goal, and W-goal, respectively. I-goal, which is described as G:I, represents what a learner is expected to acquire through the collaborative learning session. Y⇐I-goal, which is described as G:Y⇐I, represents the means to attain I-goals. Both I-goals and Y⇐I-goals are personal goals for a learner. W-goal expresses the situation being set up to

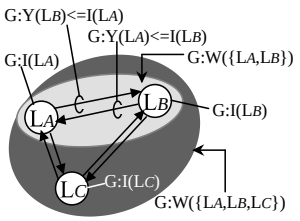

Fig. 2. Learning Goal Ontology

[1] Notation: the schemata define the W-concept and the U-concept. The W-concept has entity a, which is an instance of the concept P-concept, as a part. The entity a plays a specific role (Role-name) in the W-concept. The concept P-concept has a semicircle on the right sides. It means the concept is defined in other schema. The L-concept is a specification of the U-concept, and the U-concept is a generalization of the L-concept.

Table 1. I-goals

I-goal		Definition	Src.
Acquisition of Content-Specific Knowledge		To add new knowledge concerning the target domain to existing schemata, to understand it, and then to (re) construct knowledge structure.	[2, 4, 5, 7, 8, 19]
	Accretion		
	Tuning		
	Restructuring		
Development of Cognitive Skill		To get knowledge concerning cognitive skills such as diagnosing and monitoring, to practice them, and then to refine them.	[3, 18, 20]
	Cognitive stage		
	Associative stage		
	Autonomous stage		
Development of Metacognitive Skill		To get knowledge concerning metacognitive skills for observing self-thinking process, diagnosing it and regulating or controlling of self-activity, to practice them, and then to refine them.	[10, 18]
	Cognitive stage		
	Associative stage		
	Autonomous stage		
Development of Skill for Self-Expression		To get knowledge concerning the skills for externalizing self-thinking process and presenting the learner's self-perspectives, to practice them, and then to refine them.	[4, 21, 22]
	Cognitive stage		
	Associative stage		
	Autonomous stage		

attain Y⇐I-goals and we describe the goal as G:W. W-goal is a common goal characterizing the whole group.

Fig. 2 represents learning goals in a group where three learners: L_A, $L_B$and $L_C$are participating. Learner $L_A$has an I-goal which is attained through this collaborative learning session and this goal is described in the Fig. 2 as G:I(L_A). Both $L_B$and $L_C$have I-goals, and they are represented as G:I(L_B) and G:I(L_C) respectively. G:Y(L_B)⇐I(L_A) is a Y⇐I-goal between $L_A$and $L_B$observed from L_A's viewpoint. In other words, it means the reason why $L_A$interacts with L_B. Concerning this interaction between $L_A$and L_B, there is also a Y⇐I-goal observed from L_B's viewpoint. That is, it is the reason why $L_B$interacts with L_A. This Y⇐I-goal is represented as G:Y(L_A)⇐I(L_B). Both G:I(L_A) and G:Y(L_B)⇐I(L_A) are personal goals of L_A. G:W(L_A, L_B) is a W-goal of the learning group (L_A, L_B). G:W(L_A,L_B,L_C) is a W-goal of the learning group (L_A, L_B, L_C).

3.2 Identification of Learning Goals

In this section, we identify goals for collaborative learning for each of the three categories based on learning theories. Tab.1 shows the I-goals. We can expect learners to acquire not only new knowledge concerning problems they solve, but also cognitive skills, meta-cognitive skills, and skills for self-expression through the collaborative learning session. The process to acquire a specific knowledge includes three qualitatively different kinds of learning[19]: Accretion, Tuning, and Restructuring. Accretion is to add new information to a learner's preexisting schemata, and to interpret the information in terms of relevant preexisting schemata. Tuning is to understand the knowledge through applying the knowl-

Table 2. Y⇐I-goals

Y⇐I-goal	Definition	Src.
Learning by Observation	Learning indirectly by observing other learners' learning processes	[2]
Learning by Self-Expression	Learning by externalizing self-thinking process, such as self-explanation and presentation.	[4]
Learning by Teaching	Learning by teaching something he/she already knows to other learners	[7, 8]
Learning by being Taught	Learning directly by being taught by other learners	[7, 8]
Learning by Apprenticeship	Learning by observing other learners' behavior and then imitating it.	[6]
Learning by Practice	Learning by applying knowledge or skill to a specific problem	[15]
Learning by Diagnosing	Learning by diagnosing other learners' learning or thinking processes	[5]
Learning by Guiding	Learning by demonstrating knowledge or skill to other learners and guiding the learners	[6]
Learning by Reflection	Learning by rethinking and observing the learner's self-thinking process.	[20–22]
Learning by Discussion	Learning by discussion with other learners	[18, 20]

Table 3. W-goals

	W-goal	Definition	Src.
M-PR	Setting up the situation for Peer Tutoring [PT]	Setting up the situation where a learner teaches something to another learner.	[7, 8]
	Setting up the situation for Anchored Instruction [AI]	Setting up the situation where a learner diagnoses another learner's problem and then solve it (Problem-based Learning)	[5]
M-SR	Setting up the situation for learning by Cognitive Apprenticeship [CA]	Setting up the situation to learn knowledge or skill as an apprentice	[6]
	Setting up the situation for sharing (Meta-) Cognitive function between learners [SC]	Setting up the situation to share cognitive or meta-cognitive function between learners based on Sociocultural Theory	[24, 25]
	Setting up the situation for sharing Multiple Perspectives [CF]	Setting up the situation to evoke a learner's reflective thinking based on Cognitive Flexibility theory.	[21, 22]
PR=SR	Setting up the situation based on Distributed Cognition [DC]	Setting up the situation where full participants, whom knowledge bases are different each other, discuss problems	[20]
	Setting up the situation based on Cognitive Constructivism [CC]	Setting up the situation where full participants discuss problems	[18]
CW	Setting up the community for Legitimate Peripheral Participation [LPP]	Setting up the the community of practice for peripheral participant	[15]
	Setting up the situation for Observational Learning [OL]	Setting up the situation to share other learners' learning processes	[2]

Note: [**] means an abbreviation for the W-goal.
e.g., The W-goal "Setting up the situation for Peer Tutoring" is abbreviated as "PT".

edge to a specific situation. Restructuring is to reconstruct the learner's knowledge structure. Concerning development of skills, there are also three phases of learning: Cognitive stage, Associative stage, and Autonomous stage[1, 9]. Cognitive stage involves an initial encoding of a target skill into a form sufficient to permit a learner to generate the desired behavior to at least some crude approximation. Associative stage is to tune the target skill through practice. Errors in the initial understanding of the skill are gradually detected and eliminated. Autonomous stage is one of the gradual continued improvements in the performance of the skill.

The learner is expected to achieve these I-goals through interaction with other learners. Tab.2 shows the Y⇐I-goals. For example, to achieve the I-goal "Acquisition of Content-Specific Knowledge (Accretion)", some learners could take the Y⇐I-goal "Learning by being Taught[7, 8]", while some learners could take another Y⇐I-goal "Learning by Observation[2]".

Tab.3 shows the W-goals. The W-goals are classified into three kinds (*i.e.,* M-PR, M-SR, and PR=SR) and one exceptional W-goal (CW) according to their structures. Next section, we describe the conceptual structure of a W-goal and each kind of W-goals.

4 Conceptual Structure of W-goal

To form a learning group means to pick up learners who join in the group as members and to assign a specific role in the group to each member. The formation should have rationale supported by learning theories. The structure of learning goals expresses the rationality. A W-goal, which is a learning goal as a whole group, provides the rationale for the interaction among the members. It means that a W-goal specifies a rational arrangement of Y⇐I-goals. Fig. 3 shows a typical representation for the structure of a W-goal. It would be more easily to understand a learning theory by preparing the structure to represent the theory and filling in each component of the structure with suitable concepts according to the theory.

To describe the specification, we classify the members into two kinds of role-holders: the members who play Principal Role (PR-members) and the members who play Secondary Role (SR-members). Each role is defined as follows:

Principal Role (PR): the most important role in a collaborative learning session. A PR-member is expected to gain main educational benefit through the session. PR is usually played by the learner who first proposed to have the collaborative learning.

Secondary Role (SR): a supporting role for the PR. A SR-member helps the PR-member attains his/her I-goal. The body of specification of a W-goal is the rational arrangement of the goals for interaction among the PR-members and the SR-members. A W-goal has two kinds of goals of interaction as follows:

SR⇐PR-goal: a Y⇐I-goal which means how and for what purpose the PR-member interacts with the SR-member.

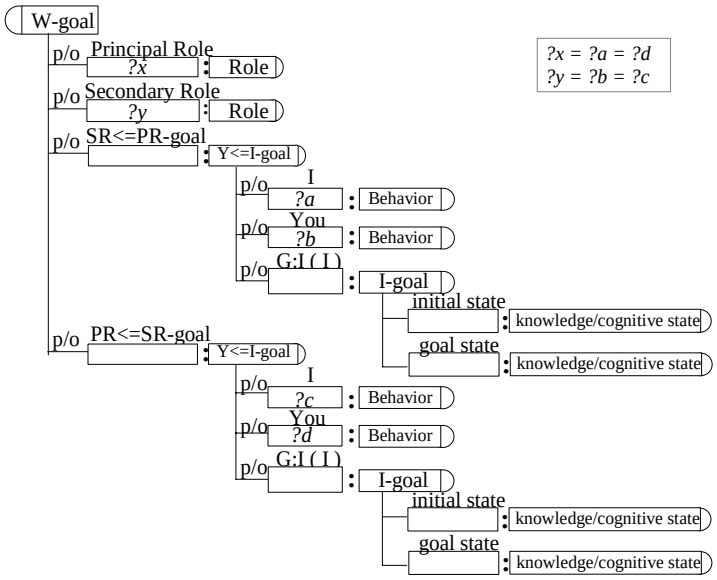

Fig. 3. Conceptual Structure of a W-goal

PR⇐SR-goal: a Y⇐I-goal which means how and for what purpose the SR-member interacts with the PR-member. In the collaborative learning session, all members of learning group are expected to get some educational benefits. So, the SR-member also has an I-goal, and the PR⇐SR-goal should be effective to attain the I-goal.

The entities of these goals refer to the concepts defined in the Y⇐I-goal Ontology. The conditions, which are proper to each W-goal, can be added to the concepts, if necessary. Each of the Y⇐I-goals referred to by SR⇐PR-goal and PR⇐SR-goal consists of three components as follows:

I: a role to attain the Y⇐I-goal. A member who plays "I role" (I-member) is expected to attain his/her I-goal by attaining the Y⇐I-goal.
You: a role as a partner for the I-member.
G:I: an I-goal which means what the I-member attains.

We classify the W-goals into three kinds of W-goals and an exceptional W-goal: M-PR, M-SR, PR=SR, and CW. The following classification of the W-goals depends on the number of the components PR and SR.

M-PR: The W-goals of M-PR type can have plural PR-members and single SR-member.
M-SR: The W-goals of M-SR type can have plural SR-members and single PR-member.
PR=SR: The W-goals of PR=SR type have only one role for members. In this type W-goal, each member joins in a collaborative learning session on an equal footing: they have the same I-goal, and the same Y⇐I-goal is expected for among the members. So we can regard each member as either PR-member or SR-member.

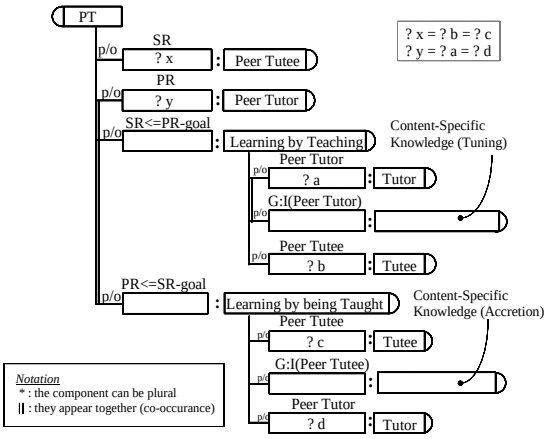

Fig. 4. PT

Fig. 4 represents the W-goal "Setting up the situation for Peer Tutoring (PT)" as an example of the M-PR type W-goal using the structure shown in Fig. 3. According to the theory of Peer Tutoring, main educational benefit by Peer Tutoring is that a learner understands a knowledge more deeply by explaining the knowledge to another learner[7, 8]. A learner, who explains the knowledge, is expected to gain the main benefit, and the benefit corresponds to the I-goal "Acquisition of Content-Specific Knowledge (Tuning)[19]". So, the PR is "Peer Tutor", SR⇐PR-goal is "Learning by Teaching", and G:I(Peer Tutor) is "Acquisition of Content-Specific Knowledge (Tuning)" in Fig. 4. On the other hand, "Peer Tutee", who is the partner of "Peer Tutor", is expected to acquire a new knowledge by being taught from the member who plays "Peer Tutor". The SR is "Peer Tutee", PR⇐SR-goal is "Learning by being Taught", and G:I(Peer Tutee) is "Acquisition of Content-Specific Knowledge (Accretion)".

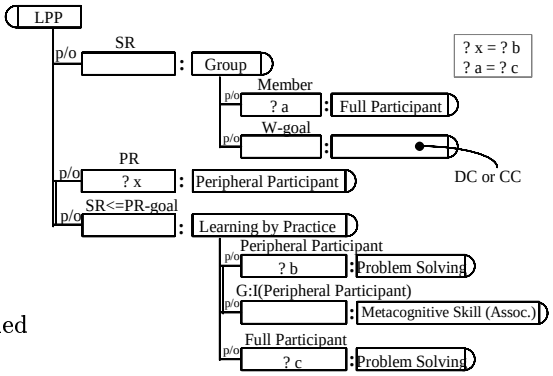

Fig. 5. LPP

The members solve problems and perform assigned tasks in the collaborative learning session. They are expected to get a few educational benefits as secondary effects through the session[14]. For example, a member could develop his/her cognitive skills (*i.e.,* educational benefit), while he/she solves a problem in physics (*i.e.,* assigned task) with other members. In the M-PR type W-goal, the SR-member mainly solves a problem with the PR-member's help. The PR-member is expected to gain an educational benefit from the experience of helping other member. On the other hand, the PR-member mainly solves a problem with the SR-member's help in the M-SR type W-goal. The role of main problem-solver should be assigned to single member, and the role of helper can be assigned to multiple members. For example, in the situation

of Peer Tutoring we mentioned above, the role of main problem-solver is "Peer Tutee" (SR) who wants to get a new knowledge to perform assigned tasks, while the role of helper is "Peer Tutor" (PR)[7, 8]. So, the number of members who play "Peer Tutee" should be single, the number of members who play "Peer Tutor" can be multiple, and the W-goal "PT" is identified as the M-PR type.

A W-goal(W_i) can have a group, which has another W-goal(W_j), as the component SR of the W-goal(W_i). We call the W-goal(W_i) "CW-goal" which means a composite W-goal. Fig. 5 shows the structure of the CW-goal "Setting up the situation for Observational Learning (OL)[2]" as an example. A learning group to attain the CW-goal "OL" has a member as an observer (*i.e.,* its component PR). The observer requires a group as an object to observe meaningful interaction. The group is identified as SR.

Each W-goal can be expressed by a set of Y⇐I-goals and I-goals. We can identify a group formation to start an effective collaborative learning session with these goals.

5 Conclusion

We have discussed learning goal ontology which will be able to make it easier to form an effective learning setting and to analyze the educational functions for a learning group. By considering the personal and common goals, we have identified three kinds of learning goals; I-goal, Y⇐I-goal and W-goal. In this paper, we described each learning goal ontology, and the conceptual structure of a W-goal. With the ontology, it is possible to compare and synthesize the learning theories to design the collaborative learning settings.

We have been developing a multi-agent system, which we call "FITS/CL", to support collaborative learning dynamically based on the idea of "Opportunistic Group Formation (OGF)"[11, 12, 23]:

> *Opportunistic Group Formation* is a 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.

In FITS/CL, each agent should have an ability to realize the following functions:

1. Setting up appropriate learning goal for a learner,
2. Forming learning group to enable the learner to attain the learning goal, and
3. Negotiating with other agents to reach an agreement: a formation of collaborative learning group that each member of the group can get educational benefit.

It is hard to realize the function 2 for the agents, even if each agent can realize the function 1 based on its learner model. Our learning goal ontology is useful for the function 2. By representing group formation suggested by many learning theories using the learning goal ontology, the agents can form a learning group according

to learning theories. The agents only look for the W-goals which include a specific I-goal as their component. Concerning the function 3, the agents cannot negotiate or reach an agreement if there is no criterion for the educational benefit. Our learning goal ontology enables the agents to infer educational benefit before the collaborative learning session starts, and justifies the agent's proposal by learning theories.

Future work includes identification of learner's role appeared in collaborative learning session and description of conditions to select a learner appropriate for each role.

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