

# Is a Learning Theory Harmonious with Others?

*To form Effective Collaborative Learning Groups with Ontological Engineering*

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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 the outline of a system of concepts concerning learning goals expected to attain by learners through collaborative learning process with justification by the learning theories. We propose possibility that theory-based learning groups can be combined into one in order to help a learner attain his/her learning goals and showed an example of effective learning group formation which is formed by combining multiple theory-based learning groups. With the ontology, it will be possible to compare and synthesize the learning theories to design the collaborative learning settings.

**Keywords: Ontology, Collaborative Learning, Distributed Learning Environments**

## 1 Introduction

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.

We have discussed item 1 in our previous papers[10, 11], 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[19], Self-regulated learning[9], Situated learning[15, 16], Cognitive apprenticeship[5], Distributed cognition[21], Cognitive flexibility theory[22, 23], Sociocultural Theory[25, 26], Zone of proximal development[25, 26], 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 supported by these learning theories[12, 14, 24]. We call the system of concepts "Collaborative Learning Ontology". 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. In this paper, we focus on "Learning Goal Ontology" which is a part of the Collaborative Learning Ontology.

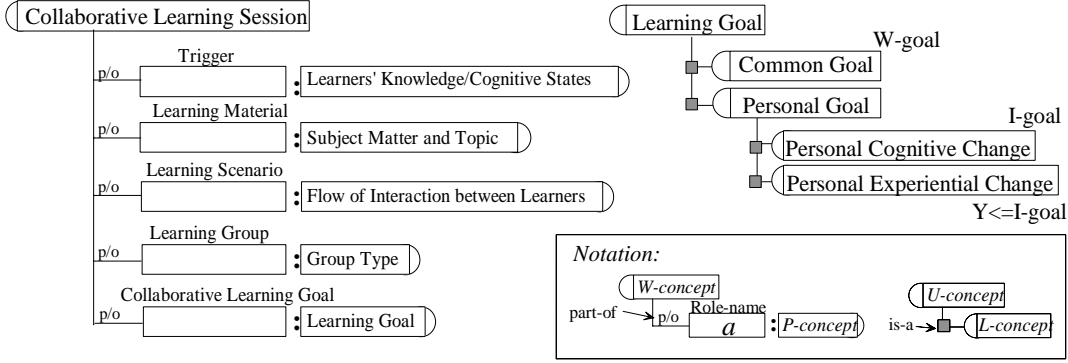


Fig. 1. Collaborative Learning Ontology

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 some learning goals.

To help a learner obtain a specific educational benefit we can find several learning theories useful for the purpose and form different learning groups according to the theories. If the groups are merged into one, we may form a better learning group which is guaranteed its effectiveness by multiple learning theories. So, we also discuss the combination of learning groups supported by different learning theories.

This paper is organized as follows: we first show briefly the structure of our “Collaborative Learning Ontology” and “Learning Goal Ontology”. Then we summarize advantages and remaining tasks: how can we narrow down candidates of learning groups into one? Finally we propose a new learning group formation formed by combining multiple learning theories.

## 2 Learning Goal Ontology for Collaborative Learning

Through a survey of studies on collaborative learning, we picked up concepts to represent a collaborative learning session. 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.<sup>1</sup> Here, we concentrate on the concept “Learning Goal” which is one of the most important concepts for forming a learning group, because each learner joins in a collaborative learning session to attain some learning goals. The “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.

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,  $Y \Leftarrow I$ -goal, and W-goal, respectively. I-goal, which is described as  $G:I$ , represents what a learner is expected to acquire.  $Y \Leftarrow I$ -goal, which is described as  $G:Y \Leftarrow I$ , represents what a learner is expected to acquire through the interaction. W-goal expresses the situation being set up to attain  $Y \Leftarrow I$ -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 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.

$G:Y(L_B) \Leftarrow I(L_A)$  is a  $Y \Leftarrow I$ -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  $Y \Leftarrow I$ -goal observed from  $L_B$ ’s viewpoint. That is, it is the reason why  $L_B$  interacts with  $L_A$ . This  $Y \Leftarrow I$ -goal is represented as  $G:Y(L_A) \Leftarrow I(L_B)$ . Both  $G:I(L_A)$  and  $G:Y(L_B) \Leftarrow I(L_A)$  are personal goals of

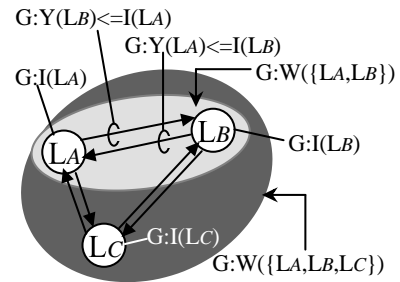


Fig. 2. Learning Goal Ontology

<sup>1</sup> 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. W-goals

	W-goal	Definition	Src.
Singleton W-goal	M-P x S-S Setting up the situation for Peer Tutoring <b>PT</b>	Setting up the situation where a learner teaches something to another learner.	[6, 7]
	M-P x M-S Setting up the situation for Anchored Instruction <b>AI</b>	Setting up the situation where a learner diagnoses another learner's problem and then solve it (Problem-based Learning)	[4]
	S-P x M-S Setting up the situation for learning by Cognitive Apprenticeship <b>CA</b>	Setting up the situation to learn knowledge or skill as an apprentice	[5]
	S-P x M-S Setting up the situation for sharing (Meta-) Cognitive function between learners <b>SC</b>	Setting up the situation to share cognitive or meta-cognitive function between learners based on Sociocultural Theory	[25, 26]
	M-P x N-S Setting up the situation for sharing Multiple Perspectives <b>CF</b>	Setting up the situation to evoke a learner's reflective thinking based on Cognitive Flexibility theory.	[22, 23]
	M-P x N-S Setting up the situation based on Distributed Cognition <b>DC</b>	Setting up the situation where full participants, whom knowledge bases are different each other, discuss problems	[21]
CW-goal	M-P x N-S Setting up the situation based on Cognitive Constructivism <b>CC</b>	Setting up the situation where full participants discuss problems	[19]
	M-P x N-S Setting up the community for Legitimate Peripheral Participation <b>LPP</b>	Setting up the the community of practice for peripheral participant	[15, 16]
	M-P x N-S Setting up the situation for Observational Learning <b>OL</b>	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".

$L_A$ .  $G:W(\{L_A, L_B\})$  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  $(\{L_A, L_B, L_C\})$ .

We have identified goals for collaborative learning for each of the three categories, and constructed I-goal Ontology,  $Y \leftarrow I$ -goal Ontology, and W-goal Ontology with justification based on learning theories.<sup>2</sup> 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 (I-goals). Each I-goal has several phases of development. It is difficult to understand from a theory what educational benefit is expected to a learner, because of lack of unified systematic terminology to represent a variety of phases. So, we adopt the terminologies used in two established findings: Rumelhart & Noman's work[15] on knowledge acquisition and Anderson's one[1] for skill development. The process to acquire a specific knowledge includes three qualitatively different kinds of learning[15]: Accretion, Tuning, and Restructuring. Concerning development of skills, there are also three phases of learning: Cognitive stage, Associative stage, and Autonomous stage[1, 8].

The learner is expected to achieve these I-goals through interaction with other learners. For example, to achieve the I-goal "Acquisition of Content-Specific Knowledge (Accretion)", some learners could take the  $Y \leftarrow I$ -goal "Learning by being Taught[5]", while some learners could take another  $Y \leftarrow I$ -goal "Learning by Observation[2]".

Table 1 shows the W-goals. The W-goals are classified into four kinds (*i.e.*, Three kinds of singleton W-goals and one Composite W-goal) according to their structures. 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  $Y \leftarrow I$ -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.

A learning theory generally argues the process that learners, who play a specific role, can obtain educational benefits through interaction with other learners who play other roles. The theories have common characteristics to argue effectiveness of a learning process focusing on a specific role of learners. So, we represent the focus in the theories as Primary Focus and Secondary Focus.

**Primary Focus (P):** a learner's role that is mainly focused in the learning theory. The learner who plays this role (P-member) is expected to gain the main educational benefit.

<sup>2</sup> The details of the ontologies are described in our previous paper[14]. Here, we show the outline of the ontologies.

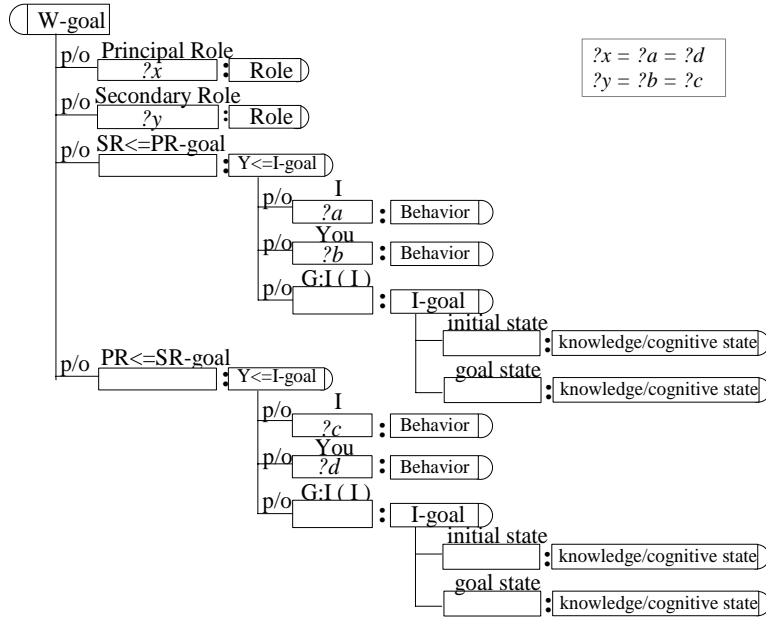


Fig. 3. Conceptual Structure of a W-goal

**Secondary Focus (S):** a learner’s role that is weakly focused in the learning theory. The learner who plays this role (S-member) is needed as a companion to enable a P-member to attain his/her learning goals.

We classify the W-goals into the following four kinds depending on the number of the components P and S.

**Singleton W-goal:** Each Singleton W-goal can exist independently.

**Multiple-P x Single-S:** The W-goal of M-P x S-S type can have multiple P-members and single S-member.

**Single-P x Multiple-S:** The W-goal of S-P x M-S type can have single P-member and multiple S-members.

**Multiple-P x No-S:** The W-goal of M-P x N-S type has only one role for its members. In this group, each learner plays a role of companion for the other learner, while he/she gains main educational benefit.

**Composite W-goal:** The CW-goal includes another group as its component S.

For example, in the situation of Peer Tutoring, there are two roles: *Peer Tutor* and *Peer Tutee*. Main educational benefit is tuning of content-specific knowledge by externalizing a learner’s knowledge[6, 7]. So, P is identified as *Peer Tutor* and S is identified as *Peer Tutee*. From the viewpoint of assigned task, the role of main problem-solver is *Peer Tutee* who wants to get a new knowledge to perform assigned tasks, while the role of helper is *Peer Tutor*. The number of members who play *Peer Tutee* (S) should be single, the number of members who play *Peer Tutor* (P) can be multiple, and the W-goal **PT** is identified as a M-P x S-S type.

A group attaining a W-goal( $W_i$ ) can have another group, which has another W-goal( $W_j$ ), as the component S of the W-goal( $W_i$ ). We call the W-goal( $W_i$ ) “**CW-goal**” which means a composite W-goal. Fig. 4 shows the conceptual structure of the CW-goal Observational Learning[2]. The learning group has *Observers* as its component P.

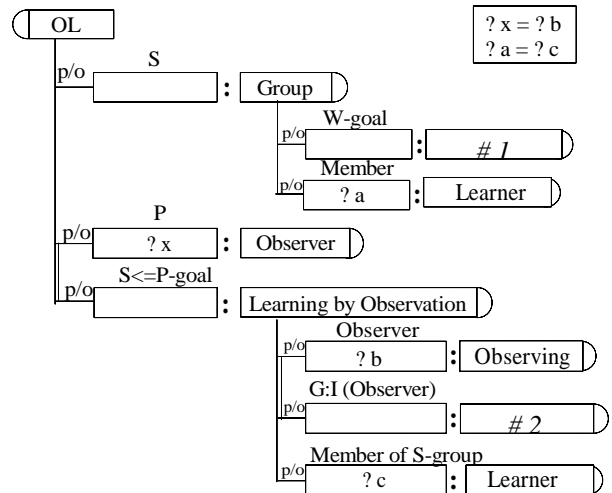


Fig. 4. An Example of CW-goal: OL

The *Observers* require a group (*i.e.*, its component S) as an object to observe meaningful interaction. In the figure, the W-goal, which is set in #1, depends on what I-goal is set in #2. For example, if accretion of content-specific knowledge is set in #2 as *Observer's* I-goal, the W-goal **PT** is recommended as S's W-goal (#1).

A W-goal has two kinds of goals of interaction as follows:

**S $\Leftarrow$ P-goal:** a Y $\Leftarrow$ I-goal which means how and for what purpose the P-member interacts with the S-member.

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

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

**I:** a role to attain the Y $\Leftarrow$ I-goal. A member who plays I role (I-member) is expected to attain his/her I-goal by attaining the Y $\Leftarrow$ I-goal.

**You:** a role as a partner for the I-member.

**G:I:** an I-goal which means what the I-member attains.

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

### 3 Advantages and Remaining Tasks of Learning Goal Ontology for Forming an Effective Learning Group

In a traditional classroom, sometimes a teacher divides students into several subgroups, and then the students start collaborative learning in the subgroup all at once. Such collaborative learning does not ensure educational benefits for every student, because it depends on a student's knowledge/ cognitive state whether collaborative learning is effective or not, and progress in learning differs from student to student.

So, we have been proposing a network-based new learning environment to support individual learning and collaborative learning dynamically. In the environment, each learner is solving problems individually with an ITS. When the ITS detects a desired situation for a learner (triggered-learner) to shift from individual learning mode to collaborative learning mode, the ITS forms an effective learning group for the learner, and then the members of the group start a collaborative learning session. In the group, not triggered-learner but every member should be ensured to attain individual learning goals through specific interaction with the other members. To encourage the interaction, every member is assigned a specific role in the group. When the members attain their learning goals, they close the session and return individual learning mode. We call the idea of dynamic group formation "*Opportunistic Group Formation (OGF)*".

With our Learning Goal Ontology we can represent the several group formations whose effectiveness is ensured by learning theories. It means that the ontology brings the following benefit: When a personal goal for a learner (*i.e.*, I-goal or Y $\Leftarrow$ I-goal) is decided, we can identify learning theories which propose learning groups to facilitate that the learner attain the personal goal. And then, we can form a specific group and identify roles assigned to the members of the group according to the theory.

If there are many theories to enable a learner to attain a specific personal goal, we can form many learning groups supported by the theories as candidates. Then, we have to narrow down the candidates to one. How can we select one?

Each learner plays a specific role in collaborative learning session. Every role has necessary conditions which should be satisfied by a learner who plays the role. The conditions will work as constraints to narrow down the candidates. If there are still some candidates after checking the conditions for role assignment, there are no rules for conflict resolution between all possible learning theories.

One might want to select one of the most profitable theory-based learning groups for a learner to attain a personal goal. Every theory expresses a different learning situation. The differences between theories do not mean the differences of the degree of effectiveness, but diversity of means to attain a goal. So, it is hard to compare a theory with the others on the effectiveness for helping a learner attain a personal goal.

There is another solution of the problem for narrowing down the candidates to one. Are learning theories exclusive each other? If the candidates can be integrated into one, a stronger learning group will appear: a learner is expected to attain a personal learning goal through some kinds of interaction, and each interaction is justified by a learning theory.

## 4 Is a Learning Theory Exclusive or Harmonious with Other Theories?

In actual learning environment, teachers often adopt the style of collaborative learning. If the group includes a member  $L_A$  whose knowledge base and/or experiences are relatively poor, it would be difficult for  $L_A$  to discuss with other members and to solve a problem collaboratively.  $L_A$  is expected to grow into a senior through practice in the group. This type of learning group is similar to the group based on the theory “LPP” which describes a process in which a newcomer grows into a senior[15,16]. Fig. 5 shows typical learning group formation the W-goal “LPP” where three learners:  $L_A$ ,  $L_B$  and  $L_C$  are participating. As a whole group, all members solve a problem collaboratively, and  $L_A$  is regarded as a **Peripheral Participant** and  $\{L_B$  and  $L_C\}$  are regarded as **Full Participants**.

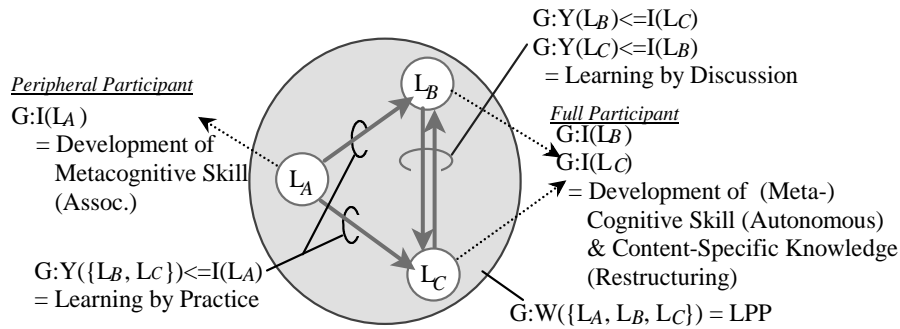


Fig. 5. An Example of Group Formation: LPP

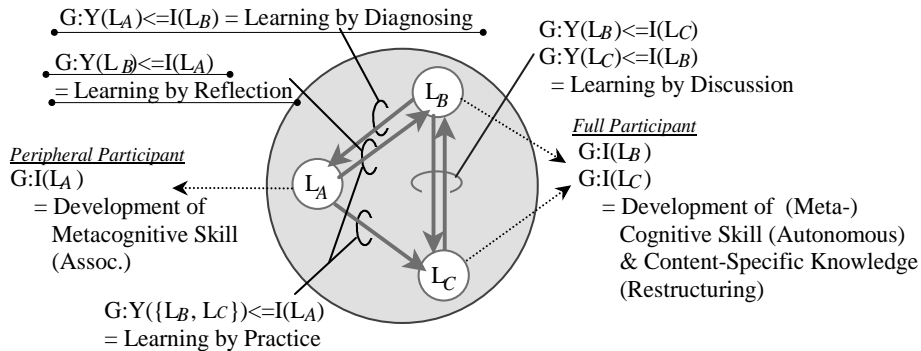
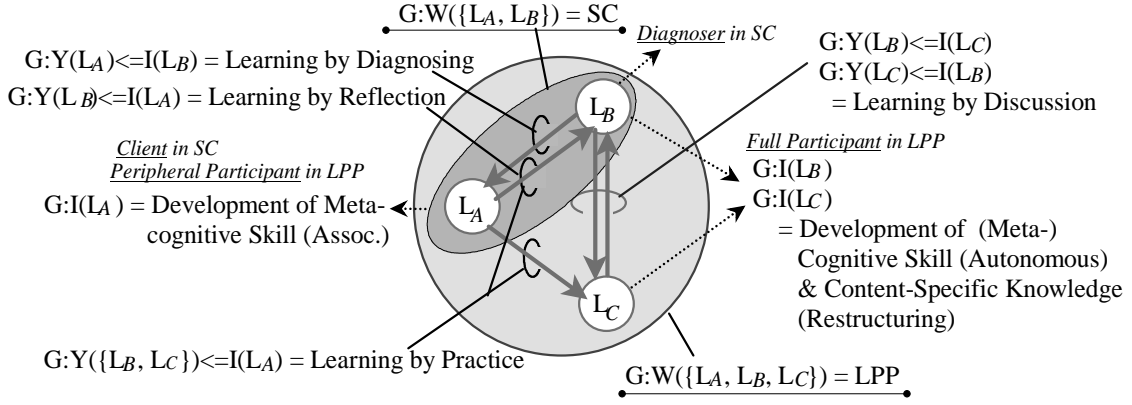


Fig. 6. An Example of Actual Learning Group

In this case, many skillful teachers will arrange for an excellent learner (*e.g.*,  $L_B$ ) to help  $L_A$  in the group. For example, when a new student comes to our laboratory, a senior student may work as a tutor for the new student. Fig. 6 shows this type of learning group formation. We can find additional  $Y \leftarrow I$ -goals between  $L_A$  and  $L_B$  in Fig. 6 as compared with Fig. 5. The teacher will expect different types of interaction between  $L_A$  and  $L_B$ , which bring additional educational benefits to them. This type of group formation can not be interpreted by a single learning theory.

In a learning group supported by “LPP”, can all Peripheral Participants grow up into full participants? According to the theory “LPP”, a learner (*i.e.*, Peripheral Participant) can acquire knowledge on the community and develop his/her (meta-) cognitive skills only by the learner’s own practice. It is not assumed the other learners (*i.e.*, Full Participants) help the Peripheral Participant grows up. It seems that there is a gap between the Peripheral Participant and the Full Participant. Especially concerning the development of (meta-) cognitive skills, a Peripheral Participant can observe not the process in which



**Fig. 7.** An Example of Combined Learning Group: W-goal LPP & SC

a Full Participant uses the skill, but input and output for using the skill. It is difficult to learn the process by observing only input and output.

Concerning the W-goals, both W-goals “AI” [4] and “SC” [26] assume to have a “poor learner” who engages to solve a problem and a “helper” for the learner. The W-goal “AI” has a **Problem-Holder**, who has a difficulty in solving a problem, and an **Anchored Instructor**, who diagnoses the Problem-Holder’s problem and gives advice to him/her. Similarly, the W-goal “SC” has a **Client**, who externalizes his/her own thinking process, and a **Diagnoser**, who diagnoses the Client’s thinking process and evaluates the process. In both W-goals, a “poor learner” is expected to attain his/her I-goal, by a “helper”’s advice. Each of these W-goals can be combined with one of the other W-goals. That is, if it is difficult for a learner to attain an I-goal, we can combine the W-goal “AI” or “SC”, and one of the other W-goals to help the learner attain the I-goal.

In the case of Fig. 6, we can interpret the group as a combination of two groups. One group ( $Group_i$ ) consists of two Full Participants ( $L_B$  and  $L_C$ ) and one Peripheral Participant ( $L_A$ ). The W-goal of  $Group_i$  is “LPP”. Another group ( $Group_j$ ) consists of a Client ( $L_A$ ) and a Diagnoser ( $L_B$ ), and the W-goal of the group is “SC”. Fig. 7 shows the combination of two groups. In this learning group,  $L_A$  is expected to participate in the session more easily thanks to the help of  $L_B$ . For  $L_B$ , it is an opportunity for diagnosing  $L_A$ ’s authentic problems and helping  $L_A$  to participate in the collaborative learning session. Through the experience, we can expect  $L_B$  to develop his/her cognitive skill in two ways. For  $L_C$ , he/she will be able to get the same educational benefit with participating in the group shown in Fig. 5, because his/her activity is equal between the both groups.

For the combination of theory-based learning groups, the role of ontology is to clarify principles of combination. In combined groups, it should be guaranteed that all members can attain their own learning goals. At this stage, we store possible patterns of combining some theory-based learning groups as a pattern library. The ontology should not only represent the patterns, but also the principles which express the design rationale why the groups can be combined into one. When we can clarify the principles, an intelligent educational support system will be able to infer an effective learning group formation based on the principles opportunistically: The group formation is not picking up an appropriate one from the static pattern library. In this paper, we have described the possibility of combination the W-goal “AI” or “SC”, and other W-goals. We have to consider the other types of combination.

## 5 Conclusions

We have discussed Learning Goal Ontology which will be able to make it easier to form an effective collaborative 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,  $Y \Leftarrow I$ -goal and W-goal. In this paper, we described the outline of Learning Goal Ontology, and summarized advantages and remaining tasks for the ontology. We proposed possibility that theory-based learning groups can be combined into one in order to help a learner attain his/her learning goals and showed an example of effective learning group formation which is formed by combining multiple theory-based learning groups. With the ontology, it will be possible to compare and synthesize the learning theories to design the collaborative learning settings.

At this stage, we mainly focus on the learning goals. Future work includes to construct ontologies on remaining concepts in Collaborative Learning Ontology. Advantage of collaborative learning includes emotional factors: *e.g.*, motivation, familiarity. It is also our future work how to treat these factors.

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