Theory-Driven Group Formation through Ontologies

Seiji Isotani and Riichiro Mizoguchi

The Institute of Scientific and Industrial Research, Osaka University,
8-1 Mihogaoka, Ibaraki, Osaka, 567-0047, Japan
isotani@acm.org, miz@ei.sanken.osaka-u.ac.jp

Abstract. Group formation plays a critical role in collaborative learning (CL). It affects the acceptance of group activities by learners and the success of the collaborative learning process. Nevertheless, proposing an effective and pedagogically sound group formation is a very complex issue due to the multiple factors that influence group arrangement. The main goal of this paper is to present an ontology that works as a framework based on learning theories that facilitates group formation and CL design. To validate the usefulness and effectiveness of this ontology we present a method to use it and the results of an experiment carried out with four instructors and twenty participants. The results suggest that our ontology can be used adequately and the concepts represented on it can positively affect the performance of individuals during group learning.

Keywords: Group formation, ontological engineering, collaborative learning.

1 Introduction

Collaborative learning (CL) has a long history in Education [14]. According to [13], over the past decades the numbers of technologies that enable people to learn collaboratively have increased considerably. In CL, group formation plays a critical role that affects the acceptance of group activities and the success of the learning process. Some researchers claim that an inadequate group formation has been the main reason for many unsuccessful applications that rely on CL [5;6]. Nevertheless, according to [17], only a few CSCL systems provide the functionality for group formation. The large majority focuses on techniques for sharing resources or on improvements of group performance (which does not guarantee an improvement of learning [3]). The policy used by conventional methods concerns situation-independent CL activities where the idea of groups composed by heterogeneous participants is always the best solution. Such policy (lower-level policy) is applicable to any situation without regulation of the group. While it has satisfactorily facilitated the use of group formation in CSCL systems [12], the lower-level policy has difficulties in supporting well-structured groups where each learner has a defined role and learning goal. This limitation may impair the chances of successful learning and complicates the analysis of the CL processes.

To overcome this problem our work deals with a higher-level policy that can be put on top of the lower-level policy to further increase the benefits of CL by bringing structure and context into the group. Thus, the main problem we are addressing is how to propose an *effective* group formation. By *effective* we mean the selection of appropriate information to propose a principled group formation that creates favorable conditions for learners to perform CL activities and helps instructors to more easily estimate the learning benefits of these activities. In order to identify the necessary information for *effective* group formation, our approach relies on achievements of the Learning Science Community (especially learning theories) and those of ontology engineering to support CL [6]. The use of ontologies aims to establish an engineering infrastructure for making theories more understandable, shareable and usable for both computers and humans. Then, we can propose techniques for reasoning on theories, facilitating the development of intelligent authoring tools for CL.

In this paper we, first, overview our theory-driven group formation concept developed to date. Second, we present our ontology and a method to use it to form groups. Finally, to validate the usefulness of this ontology, we present the results of an experiment performed with four instructors that have used our ontologies to form groups with the intent to sharpen the communication skills of twenty participants.

2 Theory-driven Group Formation

Many learning theories contribute to in-depth understanding and support of CL (e.g. LPP [8]). By selecting an adequate theory, we can provide the rationale justifying that the suggested group formation can help learners to achieve the learning goals. One could disagree that it is possible to support or enhance effective group formation by using learning theories. The authors are aware that theories have some flaws and are not "*watertight.*" However, from our point of view, learning theories can provide some essential conditions in which learners are able to learn more smoothly or effectively. By explaining the learning process, besides trying to explain what happens inside of a learner, a learning theory also gives (explicitly or implicitly), for example, the ***context*** in which the ***learning activities*** have been taking place, the target ***knowledge/skill*** that has been tackled, and the ***roles*** played by learners. Others could think that the use of learning theories to adopt some regulations (suggestions to improve the quality of CL) could harm the CL process. However, according to [3] and [15], effectiveness of CL relies on how well we can understand the multiple factors that influence group interactions and use such understanding to prescribe appropriated learning groups that facilitate meaningful interactions among learners. From such an observation, the use of theories as ***guidelines*** can increase the effectiveness of CL.

To select an appropriate theory for a specific situation is a difficult and time-consuming task. One of the reasons is the difficulty in understanding the theories because of their complexity and ambiguity. Therefore, to allow the rational use of theories to support CL, we must establish a common conceptual infrastructure on which we can clarify, at least partially, what CL is and how learning theories can facilitate the identification of a well thought out group structure. In this context, ontologies have shown significant results to represent educational theories and to use them effectively [9]. In CSCL, one of the pioneering works in using ontologies to establish a system of concepts for CL, with theoretical support, was presented in [6]. Nevertheless, previous achievements have some room for improvement. Especially, it is difficult to propose group formation in compliance with theories. To overcome such a limitation we have been working to clarify the concepts extracted from theories and to promote the adequate use of these concepts. In the next session, we present some of these concepts and explain how we can use them to propose effective group formation.

3 Ontology-Enabled Group Formation

Our work uses ontologies as a common framework to describe learning theories and CL explicitly and formally. We aim to enable theory-driven group formation that offers guiding principles that link the design of CL activities with interaction analysis. This approach allows the identifying of intended goals, roles, and strategies for a group and its members during the design process. Then, we can more easily analyze individuals' interactions to identify whether the proposed interactions were carried out successfully or not and whether learners attained the expected benefits or not. Finally, with a good analysis of interactions it is possible to acquire knowledge about learners and propose a better group formation afterwards (Figure 1).

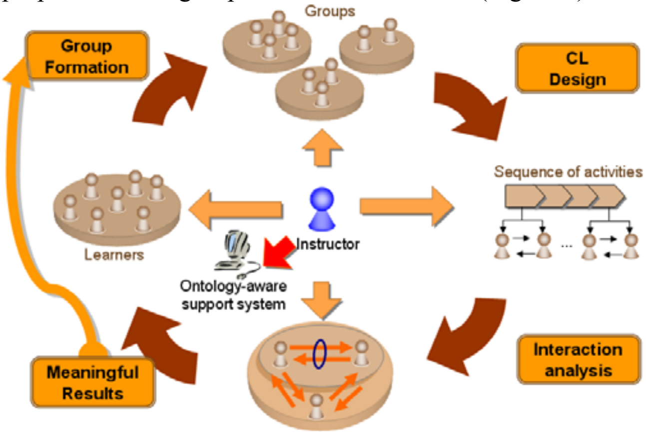

Figure 1. A full view of the total system of the theory-based group formation and analysis.

In the previous work, we extend the CL ontology to represent the relationship among interactions and learner's development, and to propose theory-compliant activities to enhance interactions among learners [7]. In this paper, we offer more expressiveness to this ontology discussing its use to support group formation.

3.1 Main Concepts for Group Formation

This section presents 3 key concepts, extracted from theories, necessary to understand how groups are formed using our ontology: *learning goal* (individual and group goal), *role* and *instructional-learning event*.

According to [1;6;10], although there is a variety of learning goals, the process of a learner's growth can be described as the process of knowledge acquisition and skill development (Table1). Thus, concerning individual goals, the CL ontology describes succinctly the learner's knowledge acquisition process and skill development process.

The process of acquiring specific knowledge includes three stages of learning: accretion, tuning and restructuring [10]. Accretion is adding and interpreting new information in terms of pre-existing knowledge. Tuning is understanding knowledge through its application in a specific situation. Restructuring is considering the relationships of acquired knowledge and rebuilding the existing knowledge structure.

Considering the development of skills, there are also three stages: the cognitive stage (rough and explanatory), the associative stage and the autonomous stage [1]. The cognitive stage involves an initial encoding of a target skill that allows the learner to present the desired behavior or, at least, some crude approximation. The associative stage is the improvement of the desired skill through practice. In this stage, mistakes presented initially are gradually detected and eliminated. The autonomous stage is the gradual and continued improvement of the skill. In this stage, the learner can perform accurately and quickly the desired behavior. *s(x,y)* is the simplified form of representing the actual stage of the learner: *x* represents the skill development and *y* represents the knowledge acquisition. For instance, *s(0,1)* illustrates that the stage of skill development is *nothing* and the stage of knowledge acquisition is *accretion*.

Table 1. Stages of learning development [6].

Individual goals (I-goal)	Stages of development	Abbreviation	Sources
Acquisition of Content-Specific Knowledge	Nothing	s(x, 0), x=0..4	[10]
	Accretion	s(x, 1) , x=1..4	
	Tuning	s(x, 2), x=1..4	
	Restructuring	s(x, 3), x=1..4	
Development of Skill			[1]
Some Types	Nothing	s(0, y), y=0..3	
- Cognitive skills	Rough-Cognitive	s(1, y), y=0..3	
- Meta-cognitive skills	Explanatory-Cognitive	s(2, y), y=0..3	
- Skill for self-Expression	Associative	s(3, y), y=0..3	
…	Autonomous	s(4, y), y=0..3	

Concerning the description of group goals in the CL ontology, there are four types: knowledge sharing, creating a solution, spread of a skill and knowledge building (or knowledge transmission). These goals are supported by some of the theories we have analyzed. For example, the Cognitive Flexibility theory supports the sharing of knowledge; and the Cognitive Apprenticeship theory supports the spread of skills.

One of the main factors that affect learners' interactions and, consequently, the achievement of learning goals is the ***role*** played by learners. A role provides pedagogical support stating functions, goals, and responsibilities that guide learner's behavior and tend to increase group stability, satisfaction and communication [15]. For example, the role of "*Tutor*" offers benefits for a learner who has knowledge about the content, but does not have much experience in using it. It is because this learner has to explain the content using his own words in order to teach (obtaining a better understanding about it). However, the same role does not bring as much benefit for a learner who understands the content well and teaches it many times. Therefore, we need to know what roles a learner can play in order to support effective group formation. Currently, the CL ontology represents 12 roles and their pre-requisites.

Finally, a learner needs the adequate context to play a role. Context is extracted from each analyzed theory and includes sequence of activities to be performed (interaction patterns [7]), participants to interact with, and so forth. Nowadays, we have analyzed seven learning theories frequently used to support CL (*e.g.* [2;8;16]).

To express the concepts presented in this section, in Figure 2 we show an updated version of our ontological structure developed previously [7]. This structure consists of two main parts: the Learning Strategy and the CL process. The Learning Strategy, composed by the members of a group and the goals of one learner (*I-role*), specifies how (*Y<= I-goal*) the learner (*I-role*) should interact with other members of the group (*You-role*) to achieve his objectives (*I-goal*). For instance, in Cognitive Apprenticeship a learner interacts with other learners to guide them during the resolution of a problem. In this case the learning strategy (*Y<= I-goal*) used by this learner is "*learn by guiding*"; his role (*I-role*) is known as a "*master role*", the role of the learner who receives the guidance (*You-role*) is known as an "*apprentice role,*" and the goals of the learner who guide (*I-goal*) are to acquire cognitive skills (and meta-cognitive skills) at an autonomous level. To play a role effectively, a learner should satisfy some necessary and desired conditions.

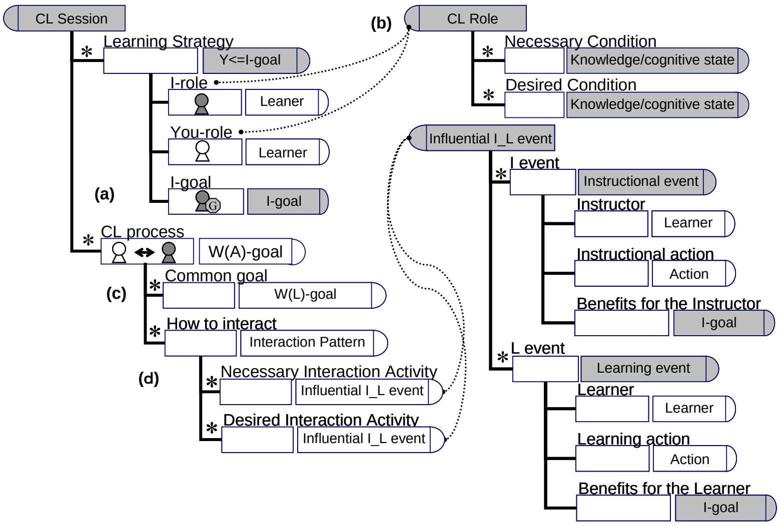

Figure 2. Part of the Ontological Structure used for group formation.

The CL Process (*W(A)-goal*) specifies the goals of the group activity (*W(L)-goal*) and the rational sequence of interactions (*interaction pattern*) provided by theories. The interaction patterns are represented by the necessary and desired interaction activities among members of a group (*e.g.* tutor and tutee). In our ontology, we describe interactions as *I_L events* (instructional-learning event), as presented by [9], for explicitly representing the interaction and its benefits from both points of view: for those who do the action and for those who receive the action. Each event is composed by an actor of an action, the action, and the benefits of the player of this action.

3.2 A Group Formation method

The question now is how to use the ontology presented in section 3.1 to form groups. A procedural example is shown on Table 2. First of all, the ontology is used as a common vocabulary to set up the CL session. After that, we use the relationship among concepts to identify the best formation that satisfies the session requirements.

Table 2. Procedure to form a group using the ontology presented in Figure 2.

Step 1 - Setup a CL session:	**Step 2 – Forming the Groups:**
1.1. To determine what the target individuals have done in the past (experience) and what they can do now (initial levels of knowledge/skills). This step aims to identify the necessities of individuals and the roles they are able to play. **1.2.** Assess the content worth learning and/or the content needed to be learned. The content should be divided in knowledge to be acquired and skills to be developed. The relationships among knowledge-knowledge, knowledge-skill and skill-skill should also be identified. **1.3.** Elect the learning goals expected to be achieved by individuals and/or by the entire group for the specific content. **1.4.** State the initial levels of knowledge/skills and the learning goals of each individual in terms of stages of learning development *s(x,y)* as indicated in Table 1. A more detailed specification of this process will be provided in future papers. Furthermore, each step described previously can be completed (at least partially) by following some instructional design strategies. Some of them can be found in [11].	There are many possibilities to form a group. Let us explore one way concerning individual goals. **2.1.** Match the individuals' goals with a CL session by looking in the *I-goal* (Figure 2a). If no match is found, it means that the theories represented in our ontology cannot help the improvement of the specific goal. However, usually there is more than one session that can help learners to achieve their goals. **2.2.** Check if learners have the necessary and desired conditions to play a role (Figure 2b). Learners with all the conditions have high-priority to join the group; learners with only the necessary conditions have low-priority; and the other learners cannot join the group, because they could harm the CL process. **2.3.** Set the group goal (*common goal*) as shown in Figure 2c; and design CL activities according to the interaction patterns that are described or prescribed by theories (Figure 2d). These patterns can be followed by learners in order to obtain the desired individual and group goals. In previous works we have shown how to design CL activities using this ontology.

Note that, unlike other approaches, the method of group formation using ontologies can provide the rationale for each choice made to form a group providing pedagogical justifications. We can support instructors by explaining why some learners should collaborate and why others should not; it is also possible to help them to set reasonable goals for learners and for the entire group considering the theoretical point of view, the learners' pre-conditions and the content to be learned; and we can ask learners to play specific roles in order to produce a more sophisticated collaboration.

4 Experiment

With the objective of obtaining information about the impact of forming groups using the theory-driven group formation with our ontologies, we designed an experiment as a proof of concepts. The main goals of the experiment were to gather information and verify (a) whether instructors can use the concepts contained in the ontology adequately, and (b) if the framework of the group formation suggested by the ontology is really relevant to the success of the CL session.

The study was carried out with 2 pairs of instructors, each pair from a different institution, and 20 participants who are expected to develop information sharing and self-expression skills. The participants are from 7 different countries of Latin America, pursuing different degrees in Japan and between the ages of 18 and 35 years old. We chose such an ill-structured environment for two main reasons: (a) these participants have been working together since 2004, but have been suffering from problems in collaborating and sharing information; and (b) in an ill-structured environment, it is easier to identify when a set of changes in the CL settings affects the success of the CL process. We expended about 2 months to complete the whole experiment.

The experiment consists of two phases. The first phase was the planning (set up) of the CL session and the second phase was its actual execution. In the first phase, instructors were asked to deal with the group problem using their own methods. After that, they should find an agreement and select or merge some of the created CL sessions. We specifically asked the instructors to give details about the content to be learned by the participants, their choices to form groups, to define goals, and to create a sequence of activities (including tools to be used). Next, the same tasks were done using our ontology with methods similar to those proposed in section 3.2.

The second phase was the application of the proposed sessions. For each CL session, about half of the participants used the scenario proposed by instructors without support of our ontology (controlled groups), and the other half used the scenario with ontological support. All groups (experimental and controlled) received support of instructors during the activities. For each session, different participants were selected to join the experimental groups according to the necessary requirements described in the ontology. All sessions were recorded and evaluated by both instructors and participants who filled out questionnaires after the sessions.

In total, it was created four CL sessions. The first one, which the main goal was to spread a specific knowledge among participants, was performed in pairs where the more knowledgeable participant should "*teach*" the content to the less knowledgeable one. Four groups followed a Peer Tutoring based CL session [4], and six groups where controlled groups that did not have any specific guideline. In the second session, the main goal was to improve skills of self-expression. It was created five groups with four members each. Three groups followed a Cognitive Flexibility based CL session [16] where learners had to expose their opinions from different perspectives. The third and fourth sessions were based in mind maps constructions and the main goal was to improve the cognitive and meta-cognitive skills and again skills for self-expression. It was created four groups with five members each. One group followed the Cognitive Apprenticeship CL session [2] with one master and four apprentices; and another one followed the LPP CL session [8] with two full participants and three peripheral participants. The group that followed Cognitive Apprenticeship theory had activities such as demonstration and guided tasks. Although the final goals were the same, the group that followed LPP theory had activities such as discussions and exchange of ideas. In Table 3, we show some interaction between learners and their educational benefits.

Table 3. Some Interactions and their benefits for two groups based on different theories.

Interaction	**Expected benefits (**From→To)		**Learning Theory**
	Role A	**Role B**	
	Master	**Apprentice**	Cognitive Apprenticeship [2]
Demonstration	s(3, 2)→s(4, 2)	s(0, x)→s(1, x); s(1, x)→s(2, x); x=0,1,2	
Instigating thinking	s(3, 2)→s(4, 2)	s(1, x)→s(2, x); x=0,1,2	
Monitoring/Coaching	s(3, 2)→s(4, 2)	s(1, x)→s(2, x); s(2, x)→s(3, x); x=0,1,2	

	Full Participant	Peripheral participant	
Requesting details	s(3, 2)→s(3,3)	s(0,x)→s(1,x); x=0,1,2	LPP [8]
Instigating discussion	s(3, 2)→s(4,3)	s(1,x)→s(3,x); x=0,1,2	
Exchanging information	s(3, 2)→s(4,3)	s(1,x)→s(3,x); x=0,1,2	

5 Results and Discussion

The interface between instructors and ontologies was mediated by the authors. The intention was to capture the necessities of users and to check the usefulness of concepts in our ontologies (and not the usefulness of a system built using ontologies). With the encouraging feedback and data obtained in the experiment, we believe it will be feasible to develop a complete ontology-aware system for CL as shown in Figure 1.

Concerning the first phase (planning), all the instructors agreed that the use of the ontology was quite helpful in obtaining a good insight about the group formation. It was discovered that many unconscious choices of instructors, in fact, have been explicitly represented in our ontology. Furthermore, instructors have considered it very informative and meaningful that the concepts in our ontology were linked with the relevant theory. Besides, it gives the rationale behind each choice to form a group and to design CL activities; in some cases, the instructors could select the theory they felt more comfortable working with. Another benefit pointed out by instructors was the facility to create and to share CL sessions. When each instructor produced their own sessions/scenarios using their own vocabulary, it was quite difficult to discuss the benefits of each one in order to find a common agreement and to merge them. Using the ontology, the sessions described by one instructor were comprehensible by the others with only small misunderstandings. Finally, the ontology was used only as guideline to help instructors propose groups with theoretical justification, thus, the instructors had the flexibility to not rely too much on the theories and add the characteristics they think the groups need in order to work effectively. It shows that the use of the ontology did not restrict instructors' action or their creativity. Instead, it helped them to focus on the main problem and to make efforts in parts where their expertise was required the most. For example, after using the information in the ontology, some participants were able to join the experimental groups and, because each session required different learner's conditions, usually we had different participants in these groups. However, sometimes there were too many participants, who could join the experimental groups. Then, instructors also had to consider: the language (to facilitate self-expression), educational background and culture (to increase heterogeneity), previous relationships with other participants (to avoid meaningless interactions), and intrinsic behavior of participants.

In the second phase, we tried to verify the differences between the controlled groups and the groups formed using our ontology (experimental groups). For each CL session, instructors checked how the participants have interacted with each other, the groups' achievements, and the benefits obtained by individuals, besides other indicators. As a result, it was observed that in most of the sessions the participants in the experimental groups had more improvement in the desired skills and the performance of the whole group was better, if compared with the controlled groups. Instructors observed that, in the controlled groups, half of the scheduled time of some sessions was filled with meaningless interactions instead of performing the necessary activities that would improve the desired skills. Furthermore, it was noted that on many occasions, members of experimental groups who had worked well together in previous sessions could not work together in controlled groups, harming the CL process. One explanation is that in the experimental groups, participants were chosen adequately (rather than randomly, as it usually happens), had defined roles and could follow well structured interaction patterns. As many studies have shown, following these regulations can decrease the chances of undesirable interactions occurring.

We observed that the experimental groups were effective in achieving the desired results. Most of the participants who joined these groups achieved their individual goals and the groups performed effectively. For example, in the session shown in Table 3, the group had as a group goal to spread the skill for building a mind map and, as one of the individual goals, the master had to develop this skill in the autonomous stage (increase his ability to build a map) while the apprentices had to develop the same skill in the associative stage (learn how to build a map adequately). The master helped the apprentices by externalizing his cognitive processes while building maps and monitoring apprentices. On one hand, the master acquired the desired goal. And on the other hand, by observing, imitating and being monitored, the apprentices developed the desired skill effectively. However, participants in the experimental groups complained that it was difficult to follow the appointed role/strategy. They argued that sometimes they had to neglect their personal behavior to get the task done as required. Those complaints are reasonable and will be taken into consideration to improve our ontology. In this same session, although some members of the controlled groups achieved their individual goals, the groups could not achieve their desired goal.

The results in this experiment suggest that the ontology-based framework of group formation can be used adequately to form effective groups. This verification is essential in order to provide intelligent systems with theoretical knowledge that clarify how learning theories can help instructors to form groups, to design CL activities and to enhance learning outcomes. The ontology presented in this work aims to represent the knowledge of intelligent educational systems that support CL, playing a central role in the decision making about ***how***, ***when***, and ***why*** we should use theories to form groups considering the multiple factors that influence the CL process.

6 Conclusions

In this paper we focused our discussion on the necessity of sophisticated group formation to set roles, goals, and activities for learners before a CL session starts. To propose effective groups, it is helpful to have a clear and sharable understanding about many learning theories and their features. However, it is very difficult for users (e.g. instructors) to have such a common understanding. Our approach calls upon techniques of ontological engineering to build ontologies that represent, explicitly and formally, the main concepts of each theory which are obtained by our interpretation of theories from group formation perspectives. We then proposed a method for using those concepts adequately. And finally, we conducted an experiment to check the usefulness of our ontology in an ill-structured environment. The results of the experiment indicate that the concepts in the ontology helped instructors to form groups and to design CL activities with theoretical justifications. Furthermore, the results also suggest that individuals in experimental groups, where each member was carefully selected and the interactions were partially moderated following the prescriptions in the ontology, performed and learned better than in controlled groups whose members were not selected so rigorously and could interact freely with others.

We believe this is a step forward in the development of the foundations of an intelligent authoring tool for CL, with a well grounded theoretical knowledge, that supports group formation, facilitates the design of CL activities, and minimizes the load of interaction analysis (Figure 1). Our ultimate goal is to develop this tool.

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