An Integrated Framework for Fine-Grained Analysis and Design of Group Learning Activities

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Abstract: To evaluate the teaching-learning process in collaborative learning sessions and its educational benefits for learners, we should analyze the interaction process during each session and select appropriate learning goals and tasks for each learner. However, the interaction process is very difficult to analyze, even for experts, and furthermore choosing appropriate goals/tasks can be even more challenging. The main objective of our work is to construct a conceptual structure based on ontology to help the interaction analysis and the learning design. We aim to make the tacit benefits for the learners explicit identifying the relationships among interactions and educational benefits. Through this conceptual structure we show how it is possible to analyze and design effective collaborative learning sessions proposing tasks and goals with justification by learning theories.

Keywords: Collaborative learning, ontological engineering, instructional design, interaction analysis

Introduction

Nowadays, collaborative learning (CL) has become a method increasingly popular used by teachers in classrooms and in e-learning environments. In spite of that, to design effective CL sessions or to analyze the interaction processes among learners, capturing what really happens in each session, has been a very complex job due to a lack of understandable models for representing what is going on [11].

Although there are many research efforts related to the evaluation/analysis of CL sessions, many just consider the quality of the group's result as a "success" criterion [3]. Nevertheless, according to Dillenbourg [6], the key to understanding collaborative learning is to gain an understanding of the wealth of interactions among the individuals. Therefore, to provide an effective CL session, establishing parameters (goals and tasks) appropriate for each learner, we need comprehensible models to represent a CL session based on interactions among individuals.

To deal with the problems presented above, our research requires techniques of ontological engineering to, based on learning theories, clarify the benefits of interactions among individuals during CL sessions. In this work we focus on unifying the models of interaction processes (sub-section 1.1) and learner's growth (sub-section 1.2), presented respectively in [11] and [12], making the relationship among the desired interaction patterns with the learner's knowledge acquisition process and the skills development process during a CL session. Through this unification, we intend to help design effective CL sessions by providing: (a) a simple and effective way to select tasks and goals for each learner and estimate their educational benefits; and (b) offering a guideline for blended learning, allowing the designer to combine different learning theories (such as Cognitive Apprenticeship, LPP, Peer Tutoring, etc.) to achieve some desired goal.

This paper is organized as follows: First, we introduce two previous models to represent collaborative learning in terms of interaction patterns and learner's development.

Next, we propose a new model which unifies the previous models and overcome some limitations of using them separately by offering new alternatives for designing, guiding and analyzing CL sessions. And finally, we present the conclusions of this work.

1. Models to Represent CL Session

The goals of many researches in CSCL (Computer Supported Collaborative Learning) include to analyze the interaction processes, considering the interaction among individuals, and to identify their educational benefits [2, 3, 6]. However, it is not common to find models that allow the explicit representation of these processes and what is much more difficult is to find such models that represent the relationship among interaction processes and educational benefits based on learning theories. Such models enable the sharing of findings and the use of computers to support the analysis and design of effective CL sessions.

The objective of the following sub-sections is to present the models developed by Inaba et al. which aid the explicit representation of a CL session in such a way that it can be understood, analyzed and shared by teachers, or even by computers. The first sub-section presents vocabularies and a model to represent the interaction processes among learners. The second presents a simplified model to represent the processes of knowledge acquisition and development of skills by the learner. These models will be used in the succeeding sections as foundations of a proposed framework for design and analysis of group activities.

1.1 A Model for Interaction Process

To represent the interaction process, Inaba et al. [11], prepared two types of vocabularies: **utterance-labels** and **utterance-types**. To label each interaction, we needed a vocabulary at a concrete level (utterance-labels). On the other hand, to characterize a CL session easily, we needed a vocabulary at an abstract level (utterance-types). To satisfy this contradiction, Inaba et al. collected great amounts of data in several CL sessions, and together with other CSCL researchers, defined labels to represent the interactions among the users (utterance-labels). Beside that, through analyses of these labels were created groups of labels, called utterance-types, to represent the interaction process at an abstract level and to distinguish and to characterize each type of CL session.

Through the definition of these vocabularies it is possible to define interaction patterns in seven types of interaction processes inspired by learning theories. Figure 1 shows an example of interaction pattern used in Cognitive Apprenticeship [4]. In this example, the interaction patterns are represented with labeled boxes (tasks/interactions described through the use of utterance-types) linked with possible transitions: necessary transitions (solid line), or desired transitions (dotted line).

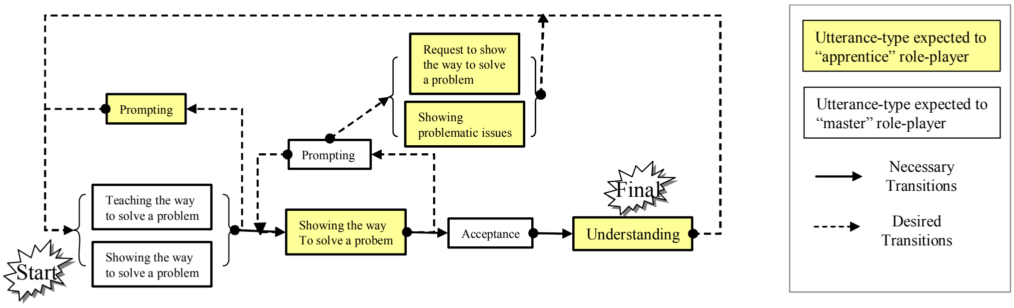

Figure 1: Example of interaction pattern: Cognitive Apprenticeship

When such models as presented in Figure 1 are available, we can explicitly represent typical interaction patterns, and thus, it is possible to compare any interaction process with interaction patterns inspired by learning theories [11]. With the construction of such a model for each desired learning theory we can determine whether the CL session was successful, based on the learners' interactions, and estimate the educational benefits for each learner.

1.2 Learner's Growth Model (LGM)

The **Learner's Growth Model** (LGM) developed by Inaba et al. [12] represents, in a simplified way, the learner's knowledge acquisition process and skill development process, explaining the relationships between learning strategies and their respective educational benefits. For such representation we have to explain more about two processes: learning of knowledge and development of skill.

The process of acquiring specific knowledge includes three qualitatively different kinds of learning: **accretion**, **tuning** and **restructuring** [14]. *Accretion* is to add and to interpret new information in terms of pre-existent knowledge. *Tuning* is to understand knowledge through its application in a specific situation. *Restructuring* is to consider the relationships of acquired knowledge and rebuild the existent knowledge structure.

Considering the development of skills, there are also three phases of learning: 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 one of gradual continued improvement in the performance of the skill.

Inaba et al. [12], developed the LGM model by representing the states of knowledge acquisition and skill development in a graph. However, the original LGM model does not represent the state of *restructuring* knowledge. Thus, to allow the representation of all states, we worked on improve the LGM model and the result is showed in Figure 2. There are twenty states to represent the levels of the learner's development at a certain moment of learning. Each state is represented by two triangles. The upper-right triangle represents the state of knowledge acquisition, while the lower-left triangle represents the state of skill development. The arrows show possible transitions between the states and *s(x,y)* is the simplified form of representing these states in our model: *x* represents the current state of skill development and *y* represents the current state of knowledge acquisition. For instance, *s(0,0)* represents the state where a learner does not have any knowledge or skills to use this knowledge; and *s(0,1)* represents the state of knowledge acquisition is *accretion* and the state of skill development is *nothing*. Using this model it is possible to represent educational benefits of several learning strategies based on learning theories as paths on a graph. Such representation will be explained in details on sub-section 2.2.

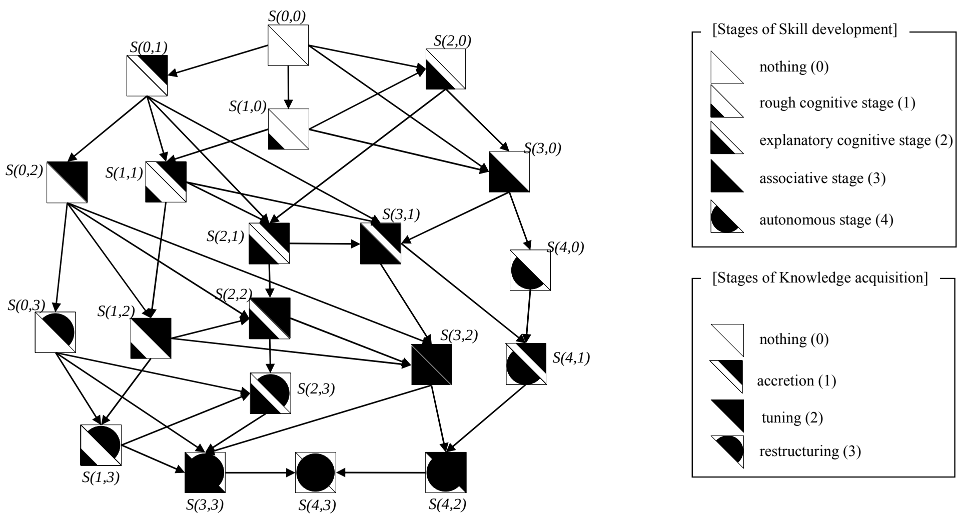

Figure 2: Learner's Growth Model (LGM)

2. Unifying the Models: Building and Merging

Until now, with the developed models presented in section 1, it is possible to successfully identify which kind of collaboration occurs in a CL session, understanding the essence of the group's interactions (sub-section 1.2), and to estimate the expected educational benefits for each member (sub-section 1.3). Nevertheless, there are some limitations when these two models are not unified:

1. There is no relation among interactions and learner's growth;
2. We can not explain a path in the LGM graph through a set of events;
3. Difficulty to blend learning theories based on the models. The meaning of blend theories is to blend different learning strategies producing a better learning process;
4. There is no way to intervene while a session is taking place. For example, if a learner, who has a misunderstanding, teaches another learner, he will transfer his problem to the other learner from the beginning until the end of the session.

Our propose is to unify these two models extending the **Collaborative Learning Ontology** [9], which represents the CL process and works as a common vocabulary. We are aiming at supporting the design and analysis of CL processes by representing and storing models of CL in terms of ontologies. Unifying these two models helps to overcome the difficulties addressed above by clarifying the relationships among interaction patterns, learning strategies and learning goals. Furthermore, we believe unifying these models is the first step to explain what a learning theory is, making tacit characteristics explicit: for instance, clarifying expected benefits, use restrictions, guidelines for leading/performing activities, in addition to other important aspects of the teaching-learning process.

2.1 Building the Foundations

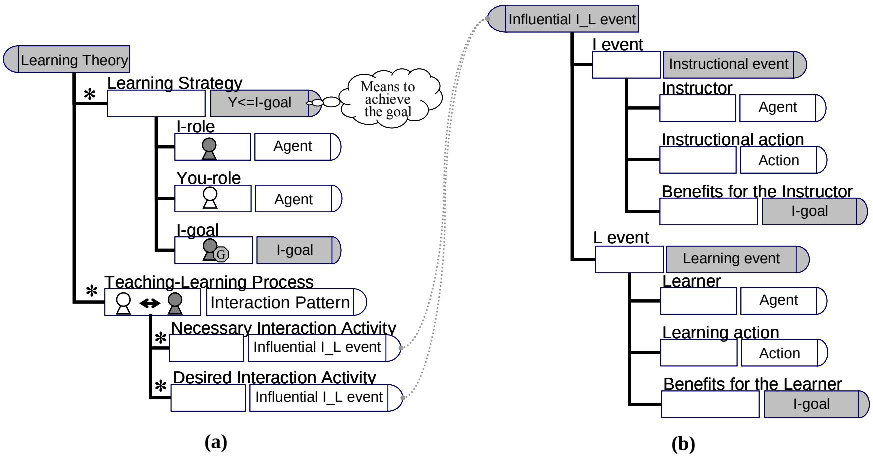

Figure 3: Example of interaction pattern: Cognitive Apprenticeship

To unify the models, first we represent the interaction patterns using a conceptual structure called Influential I_L event (Figure 3b) and after we propose a conceptual structure for representing an excerpt of the conceptual structure of Learning Theory (Figure 3a), which unifies the models.

Using the Influential I_L event structure we divided the interaction process in two events: instructional event and learning event. Every instructional event has a reciprocity relationship with the learning events. In other words, during the teaching-learning process, when a person speaks, the other listens; when someone asks a question, the other answers; and so on. Each event has a corresponding action (or actions) and its possible educational benefits to the initiator. These actions and educational benefits are directly related to the context (learning theory) in which the events and the learning strategies are executed.

The representation of the conceptual structure of Learning Theory in Figure 3a consists of two main parts: the Learning Strategy and the Teaching-Learning Process. The

Learning Strategy specifies how (*Y<= I-goal*) the learner (*I-role*) should interact with other person (*You-role*) to achieve his objectives (*I-goal*). For instance, in Cognitive Apprenticeship a learner interacts with other learners to guide him 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 "*master role*", the role of the learner who receives the guidance (*You-role*) is known as "*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. Previous works of Inaba et al. [9, 10] show the strategies (*Y<= I-goal*), learner's roles (*I-role* and *You-role*) and individual goals (*I-goal*) of several learning theories.

The Teaching-Learning Process specifies the interaction pattern of a learning theory represented by the necessary and desired interaction activities (processes) among two people (for instance, master and apprentice). As we mentioned before, we can describe interactions using the I_L event for explicitly represent the interaction and its benefits from both points of view: for those who do the action and for those who receive the action. Thus, to specify the teaching-learning process we mapped the interaction pattern presented in section 1 to fit in our influential I_L event structure. At present, with this mapping, we identified more than 13 I_L events and its respective benefits used by seven different learning theories: Cognitive Apprenticeship [4], Anchored Instruction [5], Peer Tutoring [7], Cognitive Flexibility [16], LPP [13], Socio-Cultural Theory [17] and Distributed Cognition [15]. Table 1 shows some I_L events used by Cognitive Apprenticeship (CA) and Anchored Instruction (AI), and their expected benefits for instructor and learners.

Table 1. Some Influential I_L events and its benefits in the context of two learning theories

Influential I_L events	**Event (Instructor/Learner)**	**Learning Theory**	**Expected benefits (I-goal)**	
			Instructor	**Learner**
Affirmative reaction	Acceptance/ Understanding	CA	s(3, 2) → s(4, 2)	s(2, x) → s(3, x), x=0,1,2
		AI	s(2,y) → s(3,y), y=1,2	s(x,1) → s(x,2), x=1,2,3,4
Clarify the problem	Identifying learner's problem/ Externalization of problem	CA	s(3, 2) → s(4, 2)	s(0, x) → s(1, x); s(1, x) → s(2, x), x=0,1,2
Demonstration of how to solve a problem	Demonstration/ Observing demonstration	CA	s(3, 2) → s(4, 2)	s(0, x) → s(1, x); s(1, x) → s(2, x), x=0,1,2
Instigating thinking	Argumentation/ Analyzing arguments	CA	s(3, 2) → s(4, 2)	s(1, x) → s(2, x), x=0,1,2
Monitoring	Checking/ Carrying out a task	CA	s(3, 2) → s(4, 2)	s(1, x) → s(2, x); s(2, x) → s(3, x), x=0,1,2
		AI	s(2, y) → s(3, y), y=1,2; s(z, 1) → s(z, 2), z=2,3	s(x,0) → s(x,1); s(x,1) → s(x,2), x=1,2,3,4
Notifying how the learner is	Giving information/ Processing information	CA	s(3, 2) → s(4, 2)	s(1, x) → s(2, x), x=0,1,2
		AI	s(2, y) → s(3, y), y=1,2;	s(x,0) → s(x,1), x=1,2,3,4
Requesting problem's details	Asking about problematic understanding/ Pointing out problematic understanding	CA	s(3, 2) → s(4, 2)	s(2, x) → s(3, x), x=0,1,2
		AI	s(2, y) → s(3, y), y=1,2	No expected benefit
Setting up learning context	Set information context/ Contextualization of information	CA	s(3, 2) → s(4, 2)	s(0, x) → s(1, x), x=0,1,2
		AI	No expected benefit	s(x,0) → s(x,1); s(x,1) → s(x,2), x=1,2,3,4
Showing a solution	Explanation/ Understanding explanation	CA	s(3, 2) → s(4, 2)	s(2, x) → s(3, x), x=0,1,2
		AI	s(2, y) → s(3, y), y=1,2;	s(x,1) → s(x,2), x=1,2,3,4

In spite of the influential I_L event has one main objective it is worth to point out that for each learning theory the same I_L event may have different learning purposes, and for this reason, it may have different actions and/or different expected benefits. It happens because each theory is looking for helping the learner concerning different states of knowledge and different states of skill development using different learning resources. For example, although the I_L event "*Setting up the learning context*" is used to contextualize the learner for a better understanding of the content, as we showed on Table 1, in the context of *Anchored Instruction* we expect learners to acquire some content specific knowledge, and in the context of *Cognitive Apprenticeship* we expect learners to develop some skills.

2.2 Merging the Models

Observing Figure 3 that with the representation of interaction patterns through I_L events and using our conceptual structure of Learning Theory, we can identify the interactions and their benefits for Instructor and learner in the context of a learning theory, and thus, we realize the unification of the models presented in section 1. This unification can be graphically represented by a path on the LGM graph and associating each graph's edges with the Influential I_L events which correspond to a specific change of the learner's state in the graph. In Figures 4 and 5, we use the learning theory "*Cognitive Apprenticeship*" to demonstrate how we can unify the models, clarifying which activities of the chosen interaction pattern can help the learner's development during different phases of learning.

Figure 4 shows the result of mapping the interaction pattern of Cognitive Apprenticeship (Figure 1) into Influential I_L events. The boxes are labeled with one number followed by one I_L event. As in Figure 1 we represent the transitions between boxes as necessary transitions (solid line), or desired transitions (dotted line). Each number in the boxes is used to represent the followed I_L event in our proposed model (Figure 5).

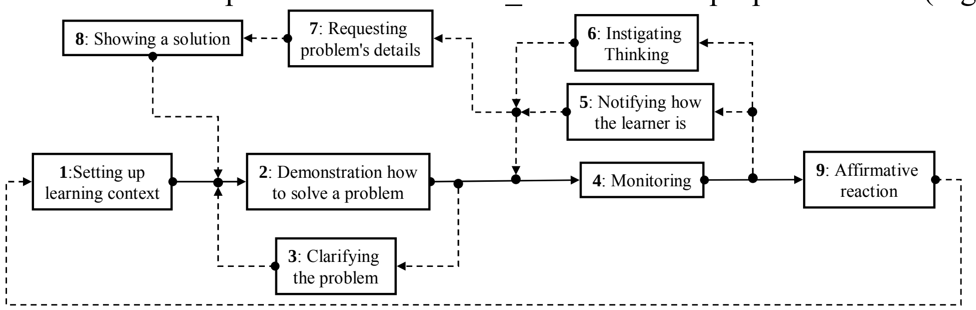

Figure 4: Interaction Pattern of Cognitive Apprenticeship represented by Influential I_L events

As one of the results of this work, we show in Figure 5 an example of the unification of the models graphically represented by improving our LGM Model (section 1.2) for Cognitive Apprenticeship augmented by the learning strategy "*learning by apprenticeship*". This model is improved by labeling each arrow with specific Influential I_L events (interactions inspired by learning theories) that facilitate the transitions among states. We call this model of **GMIP –Growth Model improved by Interaction Patterns**. The bold arrows represent the transition from one state to the other which is facilitated through this learning strategy using the labeled interactions; the dashed arrows represent the facilitation of the transition. There are two kinds of interactions: the necessary interactions, represented by a black circle, and the desired interactions, represented by a white circle. The interactions are linked by ellipses. The dashed ellipse represents a directed link between two interactions (I_L events) in Figure 4 and the full ellipse represents a no-directed link between two interactions, it means that in Figure 4 there is a cycle between these two interactions.

In the context of Cognitive Apprenticeship shown in Figure 5, the Influential I_L events "**1**:*Setting up the learning context*", "**2**:*Demonstration how to solve a problem*" and "**3**:*Clarify the problem*" are events to facilitate learners who do not have any cognitive skill, *s(0, x)*, to get some cognitive skills in rough cognitive stage, *s(1, x)*. The same events "**2**" and "**3**" above together with "**4**:*Monitoring*", "**5**:*Notifying how the learner is*", and

"**6**:*Instigating thinking*" also facilitate learners with cognitive skills in rough cognitive stage, *s(1, x)*, to achieve the explanatory cognitive stage, *s(2, x)*, and so on for the other stages.

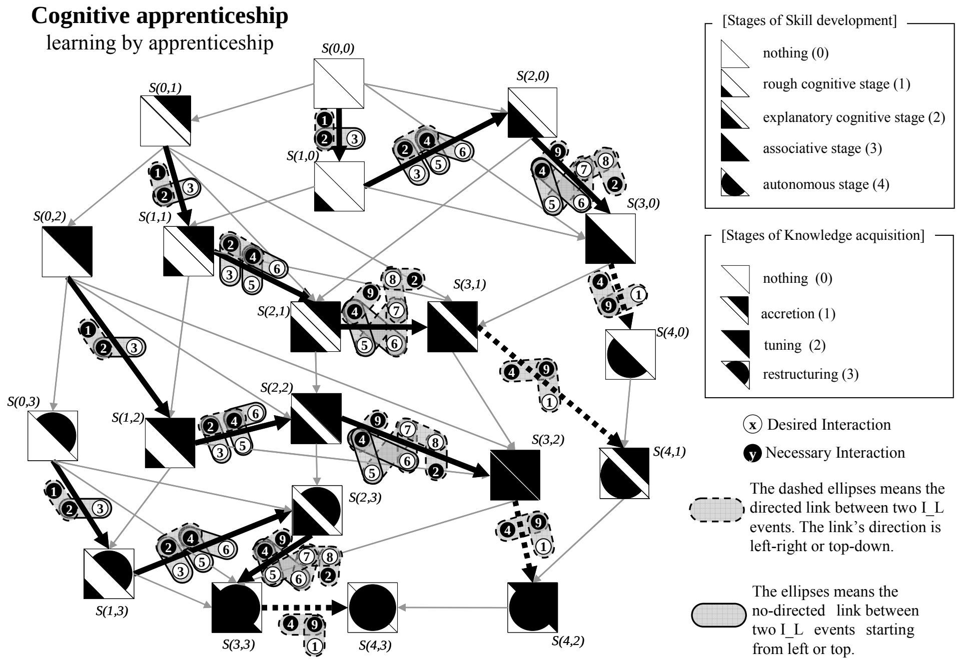

Figure 5: Example of GMIP for Cognitive Apprenticeship Model

The main contribution of our proposed model GMIP is to solve, at least partially, the problems presented in beginning of section 2. This model clarifies, more precisely, how interactions can affect learner's development, facilitating the learning design based on events. Thus, it becomes a powerful tool helping designers to select events (interactions) and roles for each learner, based on interaction patterns and learning strategies appropriate for desired learning goals and sub-goals (and vice versa). Furthermore, it is possible to offer new alternatives for designing, guiding and analyzing CL sessions. For example: (a) for each sub-goal, it is possible for the teacher to intervene, for guiding learners or analyzing collaboration outcomes while a CL session is not finished, as opposed to adjustments after it has ended, as is usually the case. Observe that we are not trying to say that it is possible to intervene in real time. What we point out is the possibility of split the collaboration in several steps (sub-goals) allowing the teacher's intervention after each step.

Another interesting example is the possibility of blend learning strategies based on our proposed model. It can be done by blending two or more strategies to achieve one desired goal. Thus, using one learning strategy, after achieving a desired sub-goal, we can change for another learning strategy to obtain another desired sub-goal that the first one can not offer. That is, with our model we can realize a guideline for blended learning theories.

With the above possible use of the GMIP model in our mind, to (a) provide input data to setup programs for designing CL sessions and to analyze group interactions; and (b) to develop programs for help collaborative learning; we have implemented the conceptual structure presented in section 2.1 using the ontology editor Hozo (available at *http://www.ei.sanken.osaka-u.ac.jp/hozo*) extending the CL Ontology [9].

3. Conclusions

The possibility of clarifying what a CL session is and to amplify its educational benefits, providing resources that facilitate its representation, design and analysis has been a great challenge. In this paper we used two models previously developed, the Interaction Pattern [11] and the Learner's Growth Model [12], and worked on clarifying the relationships among interaction patterns, learning strategies and learning goals. As a result, we have proposed an integrated model, called GMIP, which unifies the previous models through the development of a conceptual structure which extends the CL ontology and represents an excerpt of the learning theory concept. This model has been implemented using the Hozo ontology editor and can be used to develop programs for CL design and analysis.

There are, at least two, main benefits provided by our GMIP model. First, it helps the analysis of group's interactions contributing to a more precise analysis of a CL session, estimating educational benefits while a collaborative session is not finished. And second, it offers a guideline for blended learning based on learning theories which helps designers to identify more easily the role and kind of interactions (and actions) should be practiced by learners to achieve a desired goal or sub-goal in CL sessions. Our future researches include a study demonstrating some examples and possibilities to blend learning strategies semi-automatically based on GMIP model.

This is another step forward in the improvement of ontology-aware authoring systems for collaborative learning that offer help in designing learning activities based on learning theories, while providing an easy way to analyze interactions among learners and to estimate educational benefits. Our ultimate goal is to completely develop such an ontology-aware authoring system.

References

[1] Anderson, J. R. (1982) "Acquisition of Cognitive Skill", *Psychological Review*, 89(4), pp. 369-406.

[2] Barros, B., & Verdejo, M.F. (2000) "Analyzing student interaction processes in order to improve collaboration. The DEGREE approach", *Int. Journal of Artificial Intelligence in Education*, Vol. 11, pp. 221-241.

[3] Collazos, Cesar A., Guerrero, Luis A., Pino, Jose A., Ochoa, Sergio F. (2004) "A method for evaluating computer-supported collaborative learning processes", *Int. Journal of Computer Applications in Technology*, Vol. 19, No.3/4, pp. 151 – 161.

[4] Collins, A. (1991) "Cognitive apprenticeship and instructional technology". In: Idol, L., and Jones,B.F. (Eds.) Educational values and cognitive instruction., LEA..

[5] Cognition and Technology Group at Vanderbilt (1992) "Anchored instruction in science education" In: R. Duschl & R. Hamilton (Eds.), Philosophy of science, cognitive psychology, and educational theory and practice, Albany, NY: SUNY Press, pp. 244-273.

[6] Dillenbourg, P. (1999) "What do you mena by Collaborative Learnng", Collaborative Learning and Computational Approaches, Oxford: Elsevier Science, pp. 1-19.

[7] Endlsey, W. R. (1980) "Peer tutorial instruction", Educational Technology.

[8] Salomon G. (1996) "Distributed Cognitions: Psychological and Educational Considerations", Cambridge University Press.

[9] Inaba, A., Supnithi, T., Ikeda, M., Mizoguchi, R., Toyoda, J. (2000) "How Can We Form Effective Collaborative Learning Groups?", Proc. of the International Conference on Intelligent Tutoring Systems, Montreal, June, pp. 282-291.

[10] Inaba A., Mizoguchi, R. (2004) "Learner's Role and Predictable Educational Benefits in Collaborative Learning", Proc. of International Conference on Intelligent Tutoring Systems, Alagoas, pp. 285-294.

[11] Inaba, A., Ohkubo, R., Ikeda, M., & Mizoguchi, R. (2003a) "Models and Vocabulary to Represent Learner-to-Learner Interaction Process in Collaborative Learning", Proc. of the International Conference on Computers in Education, Hong Kong, pp.1088-1096.

[12] Inaba, A., Ikeda, M., & Mizoguchi, R. (2003b) "What Learning Patterns are Effective for a Learner's Growth?", Proc. of the International Conference on Artificial Intelligence in Education, Sydney, pp. 219-226.

[13] Lave, J., Wenger, E. (1991) "Situated Learning: Legitimate peripheral participation", Cambridge University Press.

[14] Rumelhart, D.E., & Norman, D.A. (1978) "Accretion, Tuning, and Restructuring: Modes of Learning", Semantic factors in cognition. LEA, pp. 37-53.

[15] Salomon, G. (1993). "Distributed Cognitions", Cambridge University Press.

[16] Spiro, R.J., Coulson, R.L., Feltovich, P.J., & Anderson, D.K. (1988). Cognitive flexibility theory: Advanced knowledge acquisition in ill-structured domains. In The tenth annual conference of the cognitive science society. Hillsdale, NJ: Lawrence Erlbaum Associates, pp 375-383.

[17] Vygotsky, L.S. (1978) Mind in Society: The development of the higher psychological processes. Cambridge, MA: Harvard University Press.