Design and Analysis of Learners' Interaction based on Collaborative Learning Ontology

Akiko Inaba, Taketoshi Tamura, Ryoji Ohkubo, Mitsuru Ikeda, Riichiro Mizoguchi, and Jun'ichi Toyoda

I.S.I.R., Osaka Universit, 8-1 Mihogaoka, Ibaraki, Osaka, 567-0047 Japan
inaba@ai.sanken.osaka-u.ac.jp

Abstract: We aim at supporting the complex instructional design process for collaborative learning. We adopt learning theories as a basis for designing, analyzing, and evaluating the collaborative learning session. We have brought the ontological engineering technique into our approach. Up to the present, we have built a collaborative learning ontology and formulated collaborative learning models in terms of the ontology. Currently, laying the ontology and the model as basis, we have been conducting a project aiming at developing various kinds of ID support system for collaborative learning. In this paper, we will describe an overview of our Collaborative Learning Ontology, and then present two systems to support the instructional design process for collaborative learning: a group formation support system, and an interaction analysis support system.

Keywords: Ontology, Learning Theory, Instructional Design, Interaction Analysis
Thematic session: Technologies for building CSCL environment (architectures, ontologies)

1. Introduction

Many researchers have recognized advantages of collaborative learning over individual learning. However, the collaborative learning is not always effective for a learner. The effectiveness depends on what a learner wants to obtain and when the learner joins in a group. For example, it is difficult to develop a learner's communication skills and to offer a learner experiences in teaching others through the individual learning. On the other hand, it is easier for a learner to acquire a new factual knowledge or a formula through the individual learning process than through the collaborative learning process. So, we should choice suitable one for what a learner wants to learn and what state the learner's knowledge is.

Then, are they the only factors to influence the effectiveness of collaborative learning? Is all we have to do to set appropriate goals to the learners and detect suitable situation to start collaborative learning session? Educational benefit that a learner gets through the collaborative learning process depends on not only the situations when the learner starts a collaborative learning session but also the process what interaction the learners do during the session. The interaction is partly influenced by relations among members of learning group, which suggests how to form an effective group for the collaborative learning is critical to ensure educational benefit to each member.

We believe it is necessary to design collaborative learning sessions conscientiously in order to make effective them. Many teachers may design the session and plan the process as preparations for collaborative learning classroom. At the implementation, they may monitor the process and coordinate it to be along the plan. When the collaborative learning session ends, the teacher may analyze the process and evaluate educational benefits that learners get through the session. There are many difficult tasks in the instructional design process for individual learning session. It will be more complex for collaborative learning, because we have to consider multiple learners and interaction among them in addition to the instructional design for an individual. So, we aim at supporting the complex instructional design process for collaborative learning. We adopt learning theories as a basis for designing, analyzing, and evaluating the collaborative learning session

There are many theories to support the advantages of collaborative learning. For instance, Cognitive apprenticeship [6], Cognitive flexibility theory [30,31], Distributed cognition [27], Observational learning [2], Situated learning [19,20], Sociocultural Theory [32,33], Zone of proximal development [32,33], and so on. If we select a learning theory from these and design a collaborative learning session according to the theory, we can expect effective collaborative learning with the strong support of the theory. A designer of collaborative learning (e.g., a CSCL system

designer, and an educational practitioner) should construct collaborative learning environments and learning plans taking the learning theories into consideration and represent what he/she intended as an explicit model of design with justification by learning theories. The understanding of learning theories used for justification is, needless to say, partial as compared with what the human expert of learning theories knows. However, we believe the learning theories, even partial, should be modeled as a basis of the instructional design for collaborative learning. The problem the designer faces is caused by difficulty in understanding the learning theories due to the lack of common and solid background concepts for collaborative learning. An ontology represents common concepts of the learning theories as a solid system of concepts.[21,22] It establishes the shared understanding among designers and systems about the model of collaborative learning which is justified with the learning theories.

In this research we are aiming at building a sophisticated ontology through a survey of existing learning theories, and supporting instructional design process for collaborative learning with the ontology. This paper is organized as follows: in section 2 we first describe the instructional design process for collaborative learning we suppose, and then, we show the outline of our Collaborative Learning Ontology in section 3. In section 4 and 5, we describe two systems using the ontology to support the instructional design process for collaborative learning.

2. Instructional Design Support for Collaborative Learning

As shown in Fig.1, in general, an instructional design (ID) process of collaborative learning consists of five phases, analyzing, designing, developing, implementation, and evaluation. First, a designer identifies the phenomena of collaborative learning, and constructs a model of collaborative learning at the analyzing phase. This phase is the foundation for all other phases of ID process, and the designer should define the problem, and identify the source of the problems. These outputs will be the inputs for the design phase. At the design phase, the designer sets learning goals to learners, figures out how the learners attain the goals, determines learning group formation, and selects tools for learners. The purpose of the developing phase is to arrange the concrete learning plans and to create learning materials. The designer develops all media that will be used in the collaborative learning, and any supporting documentation. At the implementation phase, an instructor conducts a learner along the plan, promotes his/her understanding of material, supports his/her mastery of objectives, and also ensures he/she can apply knowledge not only in educational setting but also in practical setting. Finally, the effectiveness and efficiency of the collaborative learning designed are evaluated at the evaluation phase. The evaluation should actually occur throughout the entire ID process - within phases, between phases, and after implementation.

From the viewpoint of our research objectives, we will address two important issues concerning the ID process. One is to clarify what design is and the other is to clarify the learning theories referred by the designer during the ID process. An ID of collaborative learning, in general, is too abstract to be crystallized into explicit expression in full detail.

We have brought the ontological engineering technique into our approach to tackle these hard issues. Up to the present, we have built Collaborative Learning Ontology and formulated collaborative learning models in terms of the ontology.[15,17,31] Next section, we show an overview of our Collaborative Learning Ontology.

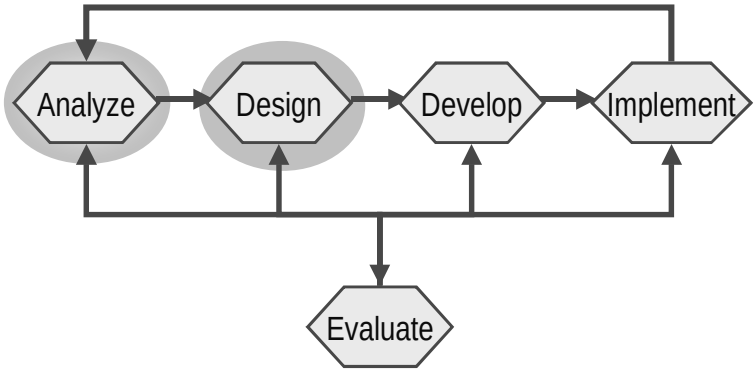

Fig.1 Instructional Design Process

3. Collaborative Learning Ontology

The ``Collaborative Learning Ontology" is a system of concepts, which acts a basis of the ID support for collaborative learning. Through a survey of a variety of studies on collaborative learning, we elicit major concepts to represent a collaborative learning session.[31] As a result, we set up eight top-level concepts to characterize the session: Trigger, Tool, Learning Material, Learning Scenario, Learning Process, Learning Group, Learner to Learner Interaction, and Learning Goal.

Here, we concentrate on the concept ``Learning Goal". We have extracted common features of phenomena, which are learning situation, interaction among learners, and educational benefits for a learner, from the learning theories. The learning theories account for such phenomena, and the phenomena can be regarded as goals by a designer. So, we use the term ``Learning Goal" to represent such phenomena. Namely, we call learning situation **W-goal**, interaction among learners **Y<=I-goal**, and educational benefits for a learner **I-goal**.

We classify the goal of the first person (***I***), that of the first person to interact with the second person (***Y***ou), and that of the ***w***hole group as **I-goal**, **Y<=I-goal**, and **W-goal**, respectively.[15]

I-goal: what a learner is expected to acquire. It can be described as a change of a learner's knowledge/ cognitive state.

Y<=I-goal: what a learner is expected to acquire through the interaction. The interaction also can be regarded as means to attain an **I-goal**. It can be described as increase of a learner's experience.

Both **I-goal** and **Y<=I-goal** are personal goals for a learner.

W-goal: a common goal characterizing the whole group. It can be regarded as a situation being set up to attain **Y<=I-goal**s.

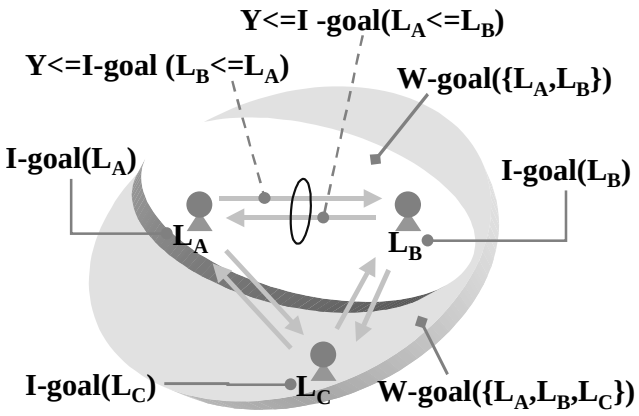

Fig.2 Learning Goals in a Group

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 that is attained through this collaborative learning session and this goal is described in Fig.2 as **I-goal** (L_A). Both L_B and L_C also have I-goals, and they are represented as **I-goal** (L_B) and **I-goal** (L_C) respectively. **Y<=I-goal** (L_B<=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 **Y<=I-goal** (L_A<=L_B). Both **I-goal** (L_A) and **Y<=I-goal** (L_B<=L_A) are personal goals of L_A. **W-goal** ({ L_A, L_B }) is a W-goal of the learning group ({ L_A, L_B }). **W-goal** ({ 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<=I-goal Ontology, and W-goal Ontology with justification based on learning theories.[14,15] We have identified four kinds of I-goals and three phases for each of them. The learner is expected to achieve these I-goals through interaction with other learners. We have pick up ten kinds of Y<=I-goals and nine kinds of W-goals.

A W-goal provides the rationale supported by learning theories 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.

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**.

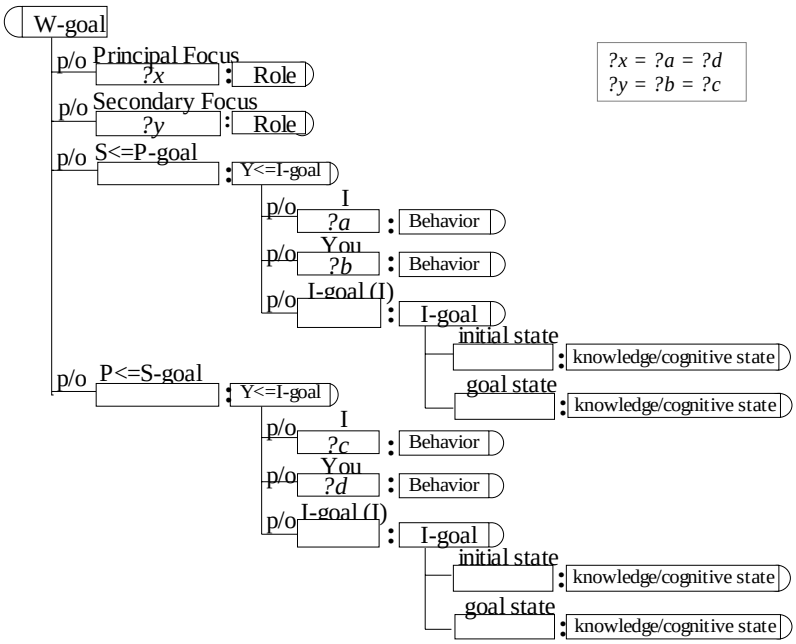

Fig 3. Conceptual Structure of a W-goal

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.

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.

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

S<=P-goal: a Y<=I-goal which means how and for what purpose the P-member interacts with the S-member.

P<=S-goal: a Y<=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<=S-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 S<=P-goal and P<=S-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.

I-goal (I): an I-goal which means what the I-member attains.

Each W-goal can be expressed by a set of Y<=I-goals and I-goals. 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.

4. Support for CL-design: A Group Formation Support System

In this section, we propose a group formation support system as an example of systems to support CL (Collaborative Learning)-design. There are many available learning theories which we can refer to form a rational learning group. The theories ensure a member of the group can get a certain educational benefit through collaboration in the group. We call the mechanism for forming a group according to a learning theory ``Theory-based Group Formation (TGF)", and develop the TGF support system which is a semi-automatic group forming system with justification by the learning theories.

Table 1: Items List for the Menu of Input-window on the TGF support system

	I-goal	Y<=I-goal	W-goal
Items	- Acquisition of Content-Specific Knowledge [2,5,7,10,11] (accretion) - Acquisition of Content-Specific Knowledge (tuning) - Acquisition of Content-Specific Knowledge (restructuring) - Development of Cognitive Skills[4,27,32] (cognitive stage) - Development of Cognitive Skills (associative stage) - Development of Cognitive Skills (autonomous stage) - Development of Metacognitive Skills [9,25,28,33] (cognitive stage) - Development of Metacognitive Skills (associative stage) - Development of Metacognitive Skills (autonomous stage) - Skills for Self-expression[30] (cognitive stage) - Skills for Self-expression (associative stage) - Skills for Self-expression (autonomous stage)	- Learning by Observation [2] - Learning by Self-expression [30] - Learning by being Taught [11] - Learning by Teaching [7] - Learning by Apprenticeship [6] - Learning by Practice [20] - Learning by Diagnosing [5] - Learning by Guiding [6] - Learning by Reflection [30] - Learning by Discussion [24,27]	- Setting up the situation for Peer Tutoring [7] - Setting up the situation for Anchored Instruction [5] - Setting up the situation for learning by Cognitive Apprenticeship [6] - Setting up the situation for sharing (Meta-)Cognitive Functions between Learners [32] - Setting up the situation for sharing Multiple Perspectives [30] - Setting up the situation based on Distributed Cognition [27] - Setting up the situation based on Cognitive Constructivism [24] - Setting up the community for Legitimate Peripheral Participation [20] - Setting up the situation for Observational Learning [2]

Fig.4 shows an overview of the system. Fig.4(a) shows an example of input-window of the TGF support system. We regard educational practitioners and educational system designers as users of the system. The users would have goals that they want learners to attain through a collaborative learning session. There are four slots in the input-window. Three upper slots are for learning goals: I-goal, Y<=I-goal, and W-goal, and the bottom one represents the learner's readiness (knowledge/ cognitive states of the learner). The users select appropriate goals and readiness from pull-down menus. Table 1 shows items in the menus, and the items are defined in the Learning Goal Ontology. Although these representations seem to be not easily understandable for users who are not experts of learning theories, the users can refer to the concrete and solid definition for each concept in the Learning Goal Ontology, and the definitions help the users understand them. If the user cannot fill all the goal-slots, the system can fill the unspecified goal-slots with appropriate ones based on the learner's current status inputted into the readiness-slot by the users.

When all the four slots are completed, the system recommends appropriate group formations for the learner to attain his/her learning goals. Fig.4 (b) shows an example of output of the TGF support system. The system shows recommended group formations with simplified figure. In the output-window in Fig.4(b), we can see three objects which represent learners: learner-A, learner-B, and learner-C. The group is labeled with the name of W-goal: ``Setting up the situation for Cognitive Apprenticeship.'' Through the interface, users can get meaningful information on design rationale of the learning group. If the user clicks a learner in the window, the system provides information on the learner: the learner's role in the group (*e.g.*, master, apprentice), the learner's behavior in the learning session (*e.g.*, guiding, imitating), educational benefits that the learner is expected to get through the session (*e.g.*, knowledge acquisition, development of cognitive skills), and suitable conditions of the learner (readiness) to play specific role in the group (*e.g.*, the learner has misconception, the learner already knows target knowledge). In the same way, if the user clicks an arrow between the learners, the system shows goal of interaction between the learners.

With the TGF support system, users can get appropriate learning group formations for learners regardless of expertise of learning theories. After that, the users will pick up appropriate learners to assign each role, and then, a concrete learning group will appear. The role assignment will be easier, because the system provides information on the suitable conditions of the learner (*i.e.*, readiness) to play a specific role. The system has ``Collaborative Learning Ontology'' as its database. The system searches the ontology to find appropriate group formations for the user's requests given from the input-window, and then, the system forms learning groups according to the ontology and illustrates them. The TGF support system can identify appropriate group formations for the users' requests using their fragmentary knowledge (*e.g.*, I-goal, Y<=I-goal) on the situation as cues for searching the ``Learning Goal Ontology''. At present, we have constructed the system, and then we will evaluate the system on its usability and practicability.

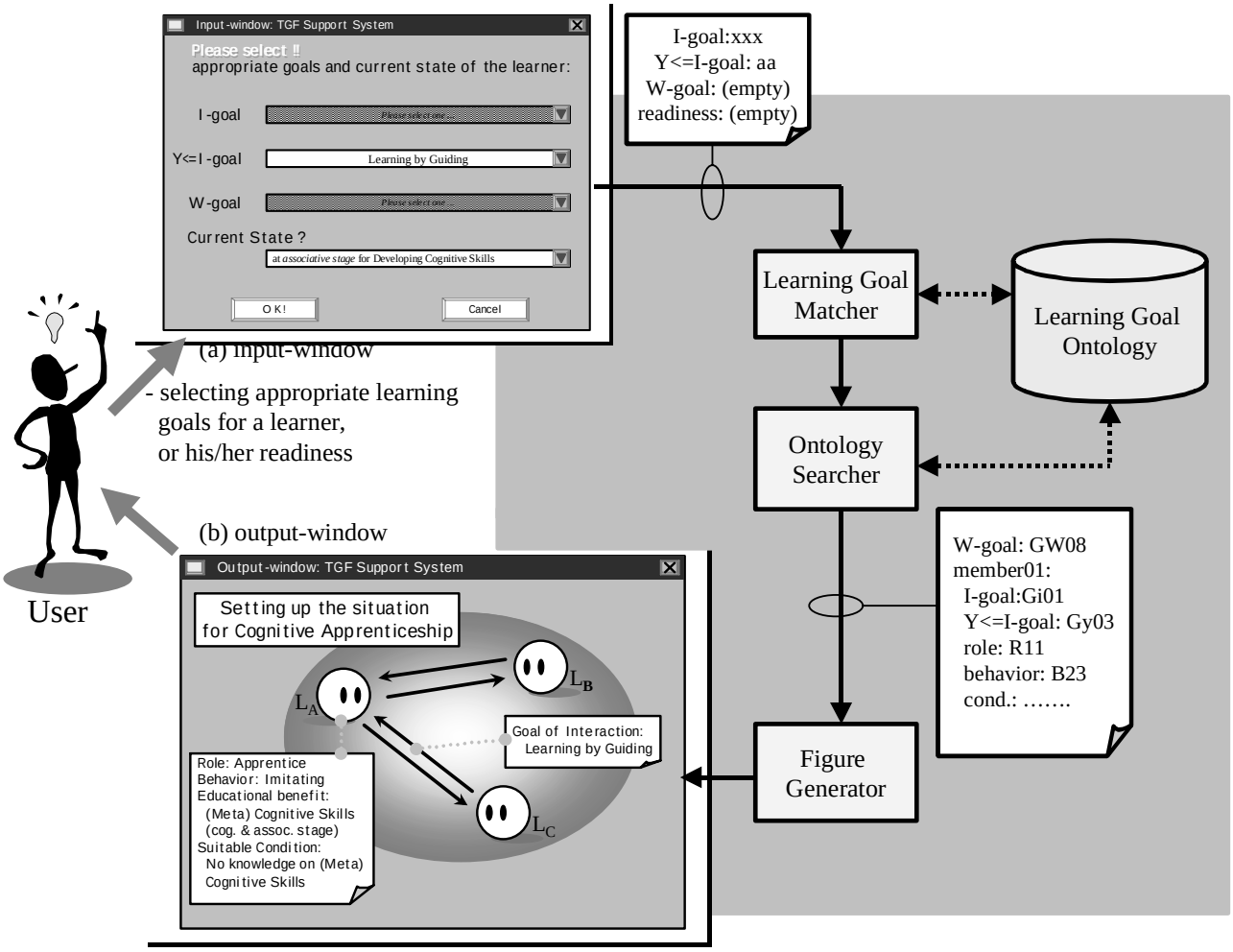

Fig.4 Overview of a Group Formation Support System: TGF support system

5. Support for CL-analysis: An Interaction Analysis Support System

In this section, we introduce the ``Theory-based Interaction Analysis (TIA)" support system as an example of the CL-analysis support system. We can observe various kinds of interaction among members of a learning group during collaborative learning session. It is difficult for even human users to analyze them in order to clarify what types of collaboration have occurred in the session and what educational benefits have been expected for the members through the session.[3,18,23,29] So, we propose an interaction analysis support system that helps users to abstract essence of interaction from raw protocol data, and to understand what types of collaboration have been occurred in the session, and then infers educational benefits expected to be gained by the members through the interaction process with Learning Goal Ontology.

Fig.5 shows the overview of the TIA support system. The input-window shows users each protocol datum of interaction among learners. The user labels each protocol with a type of utterance, *e.g.*, question, answer, explanation, and agreement, in order to abstract essence of interaction from the raw protocol data. When the user finish labeling all protocol data, the TIA support system searches the Interaction-Pattern Repository that has various kind of interaction patterns expected to appear in collaborative learning session. Each interaction pattern is represented as a series of the utterance types, and represents a typical interaction process observed in a collaborative learning session based on specific learning theory. That is, the interaction pattern characterizes the collaborative learning session that can be well-justified by a certain learning theory. Interaction-Pattern Matcher searches the repository for the most similar interaction pattern to the protocol data and then Ontology Searcher searches the Learning Goal Ontology using the interaction pattern as a cue to identify the goal of the interaction (*i.e.*, Y<=I-goal), the educational benefits expected for each learner (*i.e.*, I-goal), and the type of collaborative learning occurred in the learning group (*i.e.*, W-goal).

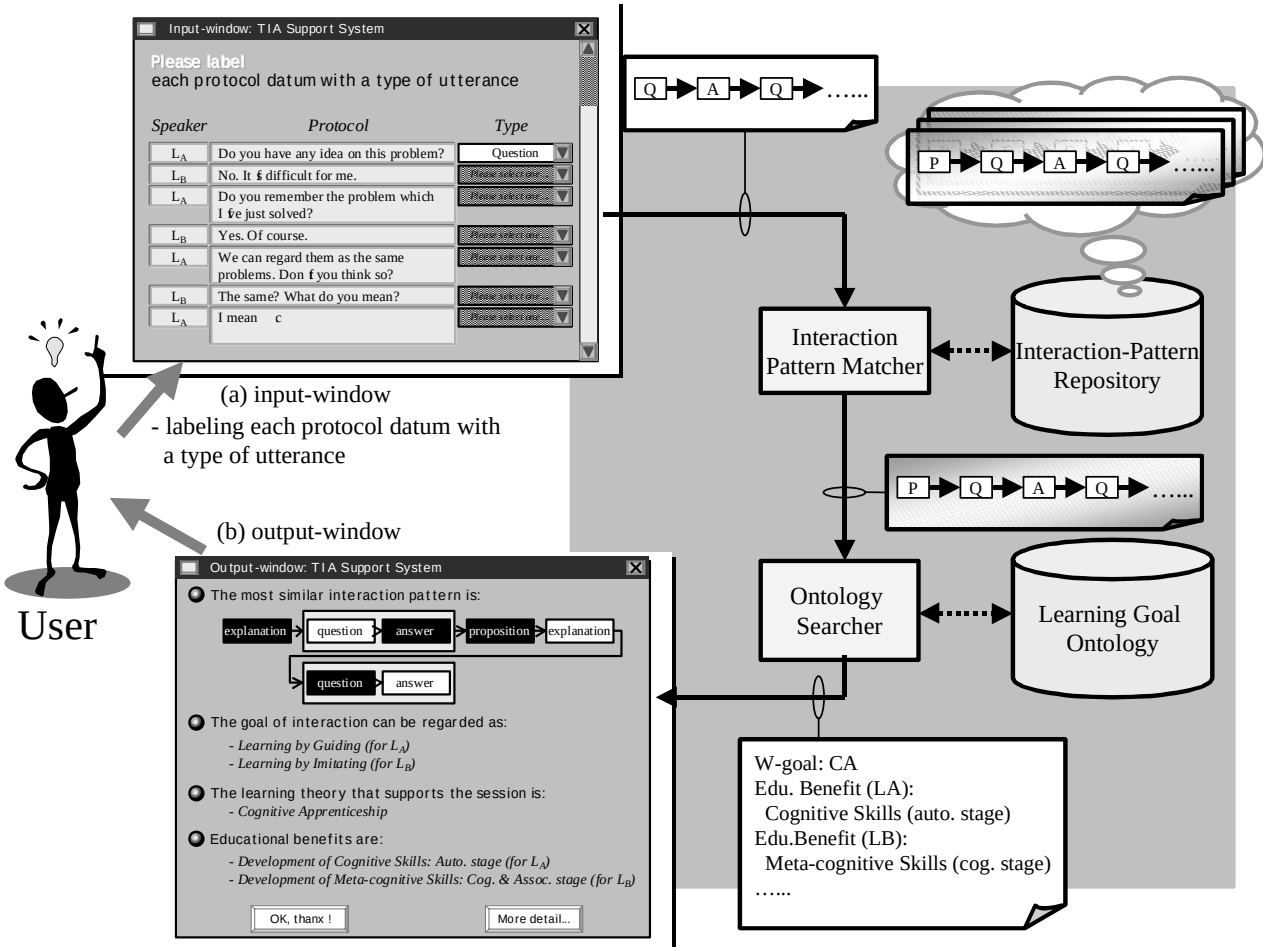

Fig.5 Overview of an Interaction Analyzing Support System: TIA support system

In the output-window, the user can get the followings:

(1) The most similar interaction pattern to the protocol data,
(2) A goal of interaction characterized by the interaction pattern,
(3) A learning theory that supports the session, and
(4) Educational benefits expected for the members of the group.

To realize the system, we have been preparing the vocabulary as a part of Dialogue Ontology to abstract the essence of interaction. First, we picked up the vocabulary from learning theories for abstracting raw protocol data. Now, we are elaborating it through some experiments. After that, we will represent interaction process among learners with the vocabulary, and construct the Interaction-Pattern Repository.

6. Conclusions

We have been conducting a project aiming at developing various kinds of ID support systems for collaborative learning. In this paper, we described the ID process for collaborative learning, and our approach to support it. We also described the outline of our Collaborative Learning Ontology, and showed two ID support systems using the ontology as examples. The TGF support system we proposed here will help both human users who don't have expertise of the learning theories and computer systems such as agents in terms of effective group formation. On the other hand, the TIA support system will help human users to analyze complex interaction process in collaborative learning. It will be useful not only to interpret what type of collaborative learning is occurred in the learning session, but also to identify why a learning session is not effective.

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