An Instructional Design Support Environment for CSCL

Fundamental Concepts and Design Patterns

Akiko Inaba, Ryoji Ohkubo, Mitsuru Ikeda, Riichiro Mizoguchi,
and Jun'ichi Toyoda
I.S.I.R., Osaka University, 8-1 Mihogaoka, Ibaraki, Osaka, 567-0047 Japan

Abstract. In this research we are aiming at supporting complex instructional design (ID) process for CSCL environment. To fulfill the aim we have been constructing an ontology to represent computer supported collaborative learning (CSCL) session. The ontology will work as both vocabulary to describe the session and design pattern referred to during the instructional design process. In this paper, we describe the ID process for CSCL, our approach to support it, and propose the ID support environment with some repositories whose data are described by common vocabulary. We show part of vocabulary and design patterns based on our Collaborative Learning Ontology as examples. Then we introduce an ID support tool using the repositories as an example. The tool will help human users to analyze complex interaction process in collaborative learning.

1. Introduction

Many of software designers of CSCL environment have been suffering with complex and subtle educational requirements offered by clients. One of major causes of the problem they face is the lack of shared understanding of collaborative learning. We do not know what design rationale of CSCL environment is and even do not have common vocabulary to describe what the collaborative learning is.

In this research we are aiming at supporting such complex instructional design process of CSCL environment. To fulfill the aim we have been constructing an ontology to represent computer supported collaborative learning (CSCL) session [14,15,16,1,31]. The ontology will work as both vocabulary to describe the session and design pattern referred to during the instructional design process. With the ontology, we can represent many kinds of CSCL sessions in terms of common vocabulary. It will facilitate users' shared understandings and reuse a learning scenario of a session [21,22]. It is important to store and provide effective learning scenarios as design patterns. We adopt learning theories as foundation to analyze, design, and develop the learning sessions. The design patterns inspired with the theories provide design rationale for CSCL design.

When we consider the theory-based instructional design for CSCL, there are many theories which would be useful for the design. For example, Cognitive apprenticeship [6], Cognitive flexibility theory [30], 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 would be able to expect effective collaborative learning with the strong support of the theory. Therefore, it is better for a designer of collaborative learning (e.g., a CSCL system designer, and an educational practitioner) to 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. The understanding of learning theories used for design 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 CSCL.

This paper is organized as follows: in section 2 we first describe the instructional design process for CSCL we suppose, and what vocabulary and design patterns are required to support the process. In section 3, we show examples of prepared vocabulary and design patterns based on our Collaborative Learning Ontology that we have been constructing based on learning theories. Then, we introduce a tool using the vocabulary and design patterns to support the instructional design process for CSCL: Interaction Analysis Support Tool.

2. Instructional Design Support for Computer Supported Collaborative Learning

As shown in Fig.1, in general, an instructional design (ID) process consists of five phases, *analyzing*, *designing*, *developing*, *implementation*, and *evaluation*. We regard ID process for CSCL as having the five phases similar to the general ID process. Here, we describe each phase of ID process for CSCL. 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 problems, 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 CSCL, and any supporting documentation in this phase. 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 CSCL designed are evaluated at the *evaluation phase*. The evaluation should actually occur throughout the entire ID process - within phases, between phases, and after implementation. Fig.1 highlights the importance of evaluation and feedback throughout the entire ID process. It also stresses the importance of gathering and distributing information in each of the five phases and shows the ID process is not a static (linear) model, but a iterative flow of activities (dynamic or spiral).

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 are helpful for the designer. An ID for CSCL, in general, is too abstract to

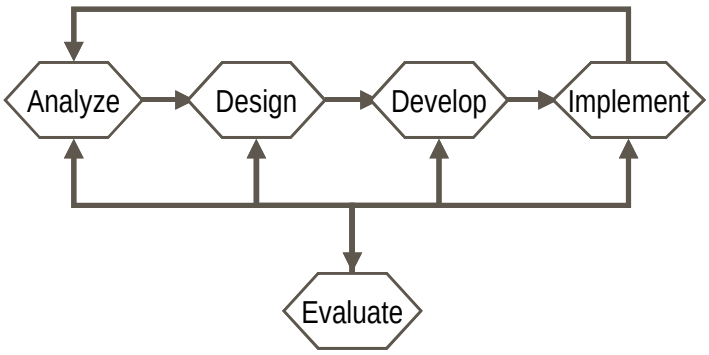

Fig.1 Instructional Design Process

be crystallized into explicit expression in full detail. We have brought the ontological engineering technique into our approach to tackle these hard issues.

We propose an ID support environment for CSCL shown in Fig.2. The environment has four repositories: *concept repository*, *design pattern repository*, *component repository*, and *abstracted case repository*.

The *concept repository* is something like a vocabulary to represent CSCL. Each concept defined in the repository is labeled with a term distinguishable from others. The top-level concepts of the repository are learning goal, learner's role, behavior, utterance type, and group formation.

A design pattern in the *design pattern repository* is a conceptual structure of a CSCL session which consists of the concepts in the *concept repository*. The pattern can be referred by designers as a design template for CSCL session design. Design patterns are classified into categories such as setting goal for learning situation (arrangement of learning goals and group formation), task (a sequence of behaviors), interaction (a sequence of utterance types), and learning environment (arrangement of tools and materials). The *component repository* stores a variety of software components or framework to build CSCL environments. The *abstracted case repository* stores learning scenarios that are arrangements of design patterns.

In the *analyzing phase*, the designer may characterize a learning process by representing the process with the terms in the *concept repository*. It will help designers to abstract a concrete learning process in order to identify what occurs in the learning session. In the *design phase*, the designer sets up a learning environment by arranging some parts in the *component repository*, and represents a learning scenario using the terms in the *concept repository*. The learning scenario arranged by the designer will be stored in the *abstracted case repository* in order to be able to re-use the arrangement. If the designer has no idea to set up a learning environment or learning scenario, the design patterns and cases will be helpful for him/her as templates. The designer can refer to the design pattern and learning scenario to set up his/her original learning scenario, modify them to fit the concrete learning session, and also use them as they are. We have been constructing Collaborative Learning Ontology which is a system of concepts to represent CSCL sessions. Particularly, we have

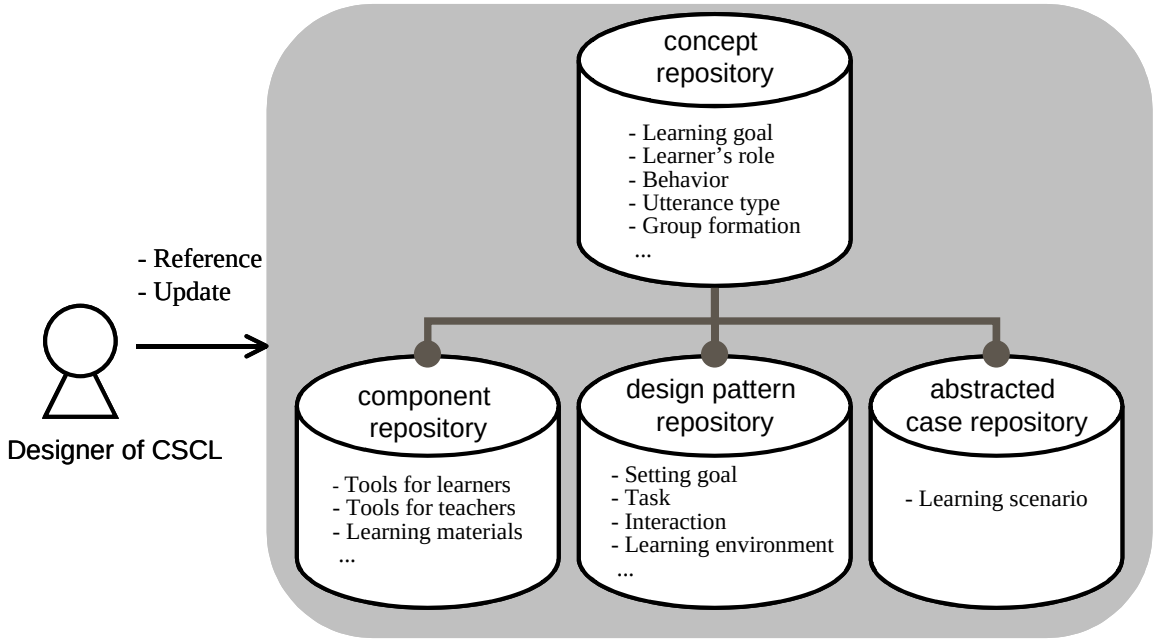

Fig.2 An ID Support Environment for CSCL

been focusing on the learning theories which would be helpful for the designer, and constructing the ontology based on the theories. So, we have been storing the *concept repository* and *design pattern repository* with some terms and design patterns using the theories as sources of useful information.

In the *developing phase*, the designers may combine some parts in the *component repository* and modify some learning materials to fit the learning session. If there is a learning scenario which describes clearly what tools and materials learners use, and how and when they use them, it is easier to create concrete learning environment by arrangement of the components. In the *implementation phase*, the learning scenario will help an instructor to understand underlying intention of the designer, and to monitor whether the process is along the design.

By the term learning scenario, we mean a representation of concrete learning process: what learners participate in the session, what goals they have, what roles they play, what tools they use, what materials they learn, and so on. Fig.3 shows a learning scenario as an example. This figure shows a learning process, which is typical type of hypothesis-testing learning session[10]: firstly, each learner hypothesizes on a problem, and has some experiments to test his/her own hypothesis, then, they discuss together results of the experiments. If a designer (of course a teacher can be the designer) decides to adopt the learning session type, the designer sets tasks 'experiment' and 'discussion'. Using the *design pattern repository*, the designer can break down the tasks into sequences of behaviors, and the behavior is defined in the *concept repository*. If there is no design pattern intended by the designer, the designer can create his/her own design pattern using the terms in the *concept repository* and stores it in the *design pattern repository*. The designer will select learning materials from the *component repository* and set learning goals. There are three kinds of learning goals: two kinds of personal goal for a learner, which are developing goal (we call **I-goal**) and interaction goal (we call **Y<=I-goal**), and a kind of group goal (we call **W-goal**). If the task will be accomplished through collaboration among learners, the designer will also set a group goal. The group goal and the personal goals are defined in the *concept repository*. In this figure, the designer assigns each learner 'acquisition of knowledge (accretion)'[26] as an **I-goal** for the task 'experiment'. For the task 'discussion', the designer assigns 'knowledge sharing'[27] as a group goal. The designer may want to know suitable educational settings, like a group formation, to attain the group goal. Then, by referring to the *design pattern repository*, the designer will find the group goal will be attained by the **setting goal** 'setting up the learning situation based on distributed cognition'.[27] The concepts which composes a design pattern '**setting goal**' are group goal **W-goal**, two types of personal goals, which are **I-goal** and **Y<=I-goal**, and learning group formation. In this case, the **setting goal** consists of the **W-goal** 'knowledge sharing', **Y<=I-goal** 'learning by discussion'[27], **I-goal** 'acquisition of knowledge (restructuring)'[26], and learning group formation 'community of practice (different aspects)'.[27] The designer will assign the personal goals to each learner. The learning group is broken down learners' roles in the group, and the role is defined in the *concept repository* as necessary conditions of a learner to perform the role and behavior the role player performs. The definitions are helpful to pick up a learner who plays the role. Up to here, it becomes clear about the session: what learners participate in the session, what roles they play, what behavior they perform, what learning materials they learn, and what educational benefits they are expected to acquire. Then, the designer will design a learning environment to enable the session. The learning environment is represented as an arrangement of tools for learners and that for teachers. In this example, the designer sets the tool 'simulation' for each learner to experiment on the problem, and the tool 'monitoring each learner's learning process' for the teacher for the first half of the task 'experiment'. For the latter half of the task, the tool

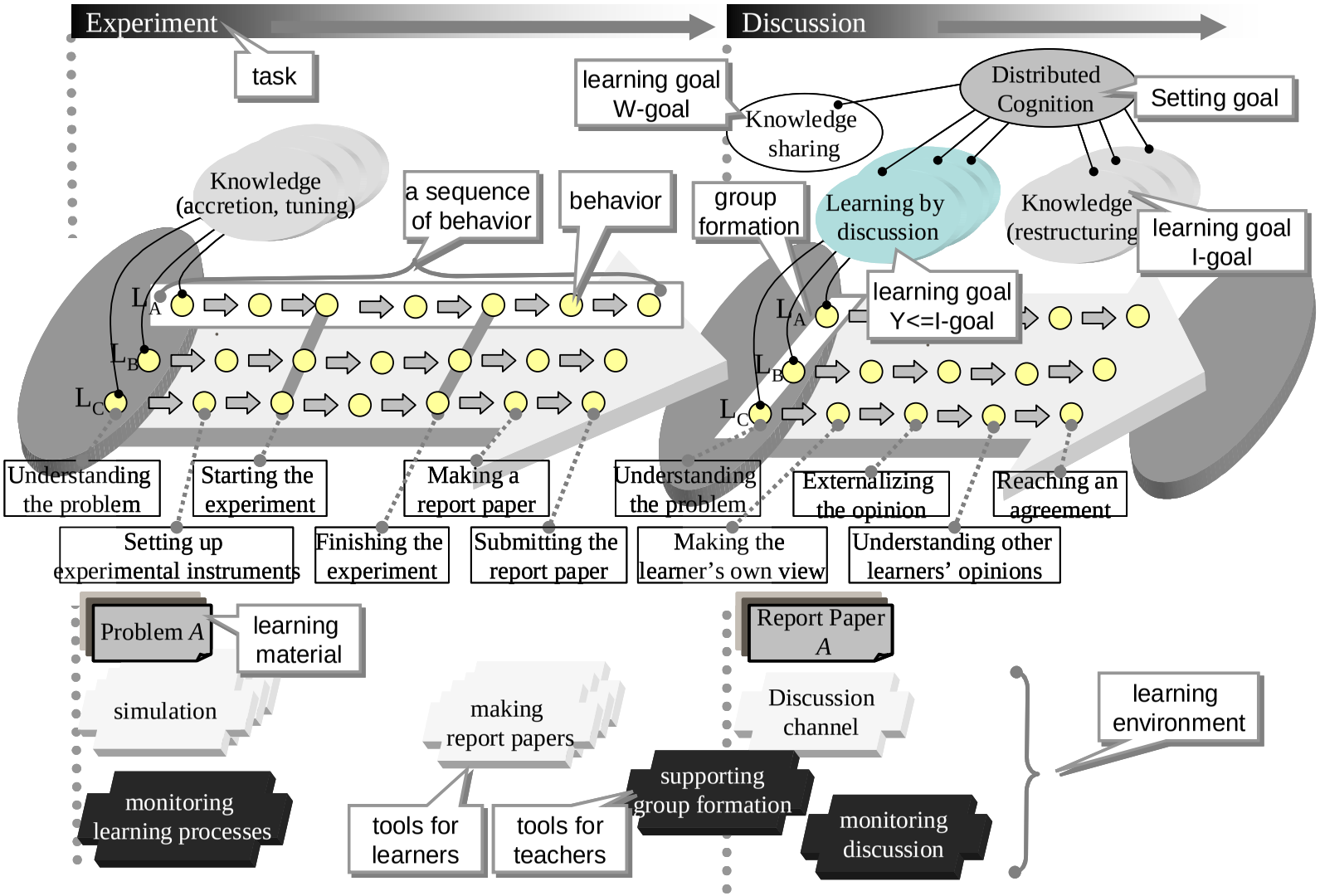

Fig.3 An Example of the Learning Scenario

'making a report paper' is set for each learner. For the beginning of the task 'discussion', the tool 'supporting group formation' is set for the teacher. Then, the tool 'discussion channel (like a chat system)' is set for the learners, and the tool 'monitoring discussion' is set for the teacher.

With a representation like this, a learning process will be represented more clearly. It will help other designers to understand learning scenarios and to re-use them. By preparing some concepts, design patterns, and components, we believe it will be easier to describe such scenario, because each concept or component works as a building block to design the scenario, and each design pattern works as a template or guideline to arrange the building blocks.

The framework of the ID support environment we proposed here will be useful for not only ID for CSCL but also individual learning. The contents of each repository in ID support environment for CSCL should be richer than that for individual learning. In the case of collaborative learning, a designer has to address multiple learners' learning processes, and interaction between the processes or the learners. In addition to vocabulary and software components for individual learning, the designer would need rich vocabulary to represent such complex learning process, and new components to realize such interaction.

3. Examples of Data in the Repositories: Learning Goals and Learning Group Formations

Up to the present, through a survey of a variety of studies on collaborative learning we have built Collaborative Learning Ontology and formulated CSCL models in terms of the ontology.[14,15,16,17,31] In this section we show some vocabulary and design patterns concerned with learning goals and learning groups based on our Collaborative Learning Ontology, as examples of data in the repositories. The vocabulary and design patterns we show here are inspired with learning theories.

First, concerning the concept `group formation', we identify a learning group as a set of specific roles. For example, in the learning theory 'Legitimated Peripheral Participation', an autonomous learner who engages in problem-solving in his/her community is called 'Full Participant', and a learner who is a new comer for the community is called 'Peripheral Participant'.[20] We call them 'roles' in a collaborative learning group. So, in the theory of LPP, the learning group is represented as a set of Full Participants and Peripheral Participants. We have elicited thirteen roles from learning theories, such as 'Master'[6], 'Apprentice'[6], 'Observer'[2], 'Client'[32], 'Diagnoser'[32], 'Peer Tutor'[7], 'Peer Tutee'[7], 'Peripheral Participant'[20], 'Full Participant'[20], and so on. Each role is defined in the *concept repository* as the necessary conditions of a learner for playing the role, and behavior the role player performs. For example, concerning the role of Full Participant, the necessary conditions are that the learner already acquired knowledge concerning a problem, can use it, and can apply cognitive skill and metacognitive skill to the discussion even if unsteadily. On the other hand, concerning the role of Peripheral Participant, the necessary conditions are that the learner already knew what cognitive skill is and what metacognitive skill is (but it is not necessary to have an experience to use the skills). Behavior of Full Participant is problem-solving, and that of Peripheral Participant is also problem-solving. The learners who play these two roles are distinguished not by their behavior but their conditions when they participate in the collaborative learning [20]. The group formations are also stored in the *concept repository*.

Second, we show the vocabulary on the concept `learning goal'. We have extracted common features of phenomena, which are development of learning community, 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 or a learner. So, we use the term ``learning goal" to represent such phenomena. Namely, we call the development of learning community **W-goal**, the interaction among learners **Y<=I-goal**, and the 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.[14,15]

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

Y<=I-goal: personal interaction goal. It represents 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.

W-goal: group goal. It is a common goal characterizing the whole group.

Fig.4 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.4 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] The concepts these ontologies have are stored in the *concept repository* as vocabulary to represent learning goals. We have identified four kinds of **I-goal**s and three phases for each of them, such as 'acquisition of content-specific knowledge (phase: accretion, tuning, restructuring)'[26], 'development of cognitive skill (phase: cognitive stage, associative stage, autonomous stage)[1,8], and so on. The learner is expected to achieve these **I-goal**s through interaction with other learners. We have pick up ten kinds of **Y<=I-goal**s, such as 'learning by teaching', 'learning by observation'[2],

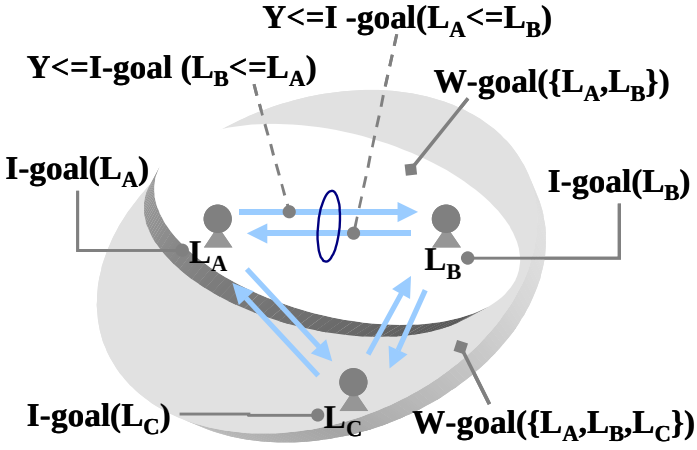

Fig.4 Learning Goals in a Collaborative Learning Session

'learning by self-expression'[32], and so on. The examples of **W-goal**s are 'knowledge sharing'[27], 'creating a solution'[24], 'spread of skills'[6,20] and so on.

There is another goal for designers to form learning groups and to set learning goals. The goal represents the designers' needs what learning situations they want to design. For example, some designers may want to realize the learning situation, where a new comer to the community learns something by his/her own practice, mentioned in the theory of LPP[20]. Some designers may want to realize the learning situation, where a knowledgeable learner teaches something to a poor learner, mentioned in the theory of Peer Tutoring[7]. We call the designers' goal **setting goal**. The **setting goal** is represented as a set of learning goals and group formation, and stored in the *design pattern repository*. Now, each **setting goal** provides the rationale supported by specific learning theory. That is, the **setting goal** specifies a rational arrangement of learning goals and a group formation. Fig.5 shows a typical representation for the structure of a **setting goal.** The **setting goal** consists of six concepts: **Common goal**, **Primary Focus**, **Secondary Focus**, **S<=P-goal**, **P<=S-goal**, and **Learning Group**. The **Common Goal** is a goal of the whole group, and the entity of the **Common goal** refers to the concepts defined as **W-goal** in the *concept repository*. Both **Primary Focus** and **Secondary Focus** are learners' roles in a learning group. 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.
Secondary Focus (S): a learner's role that is weakly focused in the learning theory. The

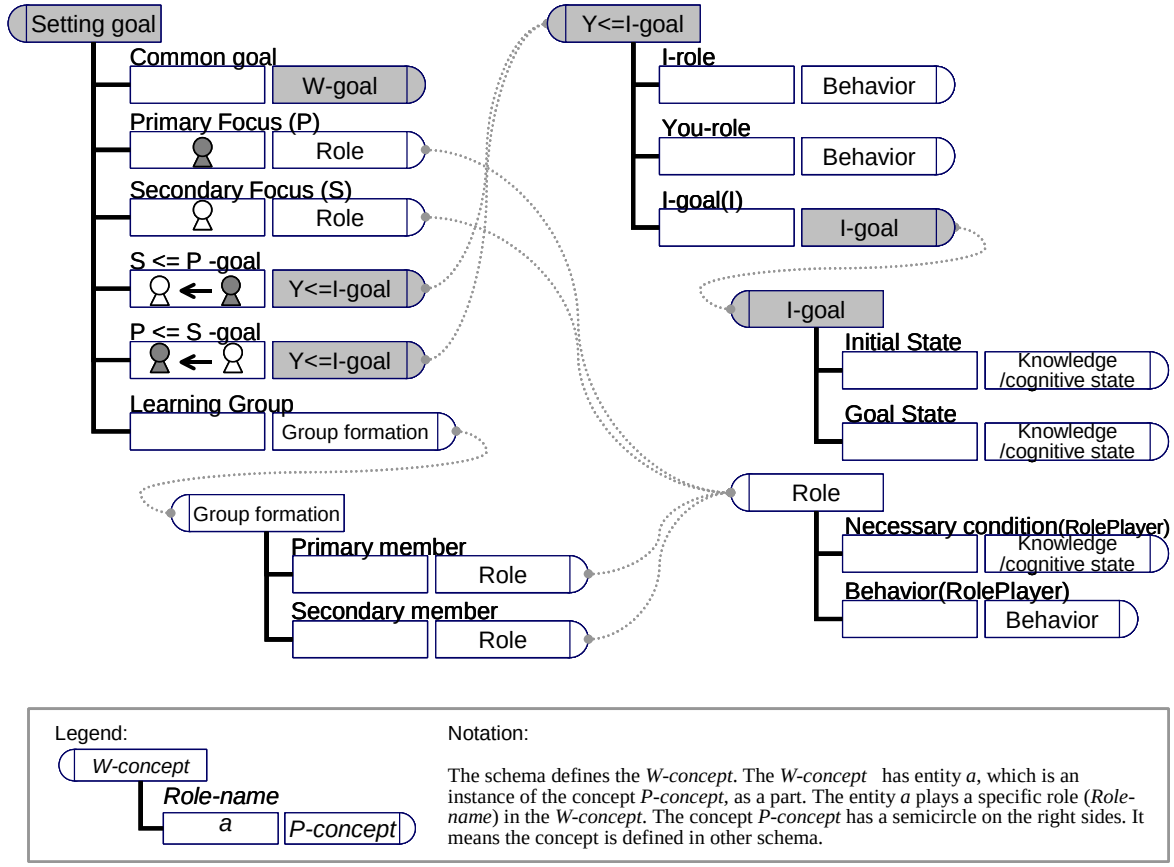

Fig.5 Structure of a Setting goal

learner who plays this role (S-member) is needed as a companion to enable the learner who plays P-role (P-member) to attain his/her learning goals.

A **setting 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 as **Y<=I-goal**s in the *concept repository*. The conditions, which are proper to each **setting goal**, can be added to the concepts, if necessary. Each of the **Y<=I-goal**s referred to by **S<=P-goal** and **P<=S-goal** consists of three concepts 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** that means what the I-member attains.

The **Learning Group** is the concept which represents a set of specific roles for learners. The entity of the **Learning Group** refers to the concept defined as **Group Formation** in the *concept repository*. A **Group Formation** has two concepts: **Primary member** and **Secondary member**.

Primary member: a learner's role as a group member that mainly contributes toward achieving the group's **W-goal**.

Secondary member: a learner's role as a group member that weakly contributes toward achieving the group's **W-goal**.

For example, the theory of LPP argues mainly the process that learners, who play the role of Peripheral Participant, can obtain educational benefits through interaction with other learners who play the role of Full Participant. So, in a learning group supported by LPP, the **Primary Focus**ed learner is Peripheral Participant, and **Secondary Focus**ed learner is Full Participant. On the other hand, the **W-goal** of the group is identified as "spread of skills" according to the theory, and a learner, who mainly contributes toward achieving this goal, would be Full Participant. So, **Primary member** is Full Participant, and **Secondary member** is Peripheral Participant. In collaborative learning, the main contributor for achieving a **W-goal** does not always get main educational benefit. It is one of distinctive features for collaborative learning, and the feature may be a factor of confusion which occurs in ID process for collaborative learning. So, we distinguish between the concept of beneficiary of personal educational benefit and the concept of contributor for achieving a common goal for the whole group.

Each **setting goal** can be expressed by a set of **W-goal**, **Y<=I-goal**s, **I-goal**s, Learners' **Role**s and **Group formation**. It would be more easily to form a learning group which is effective for learners to attain specific learning goals by preparing the structure to represent the rational arrangement and filling in each component of the structure with suitable concepts according to the theory.

4. Tools to Support ID process for CSCL

Currently, laying the ontology and CSCL models formulated in terms of the ontology as basis, we have been conducting a project aiming at developing various kinds of ID support

tools for CSCL. For example, we have been constructing a group formation support tool (TGF support tool) for the design phase, a flexible learning environment with multi-agent system (FITS/CL based on OGF)[31] for design, development, and implementation phase, learning materials authoring tool for development phase, and an interaction analysis support tool (TIA support tool) for the analyzing phase. In this section, we introduce the ``Theory-based Interaction Analysis (TIA)" support tool as an example of the CL-analysis support tool. 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 tool 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.

Fig.6 shows the overview of the TIA support tool. The input-window shows users each protocol datum of interaction among learners. The user labels each protocol with an utterance type, *e.g.*, question, answer, explanation, and agreement, in order to abstract essence of interaction from the raw protocol data. The utterance types are stored in the *concept repository*. When the user finish labeling all protocol data, the TIA support tool searches the interaction-patterns in the *design pattern repository* that has various kind of interaction-patterns expected to appear in collaborative learning session. Each interaction-pattern is represented as a sequence of the utterance types, and represents a typical interaction process observed in a collaborative learning session based on specific learning

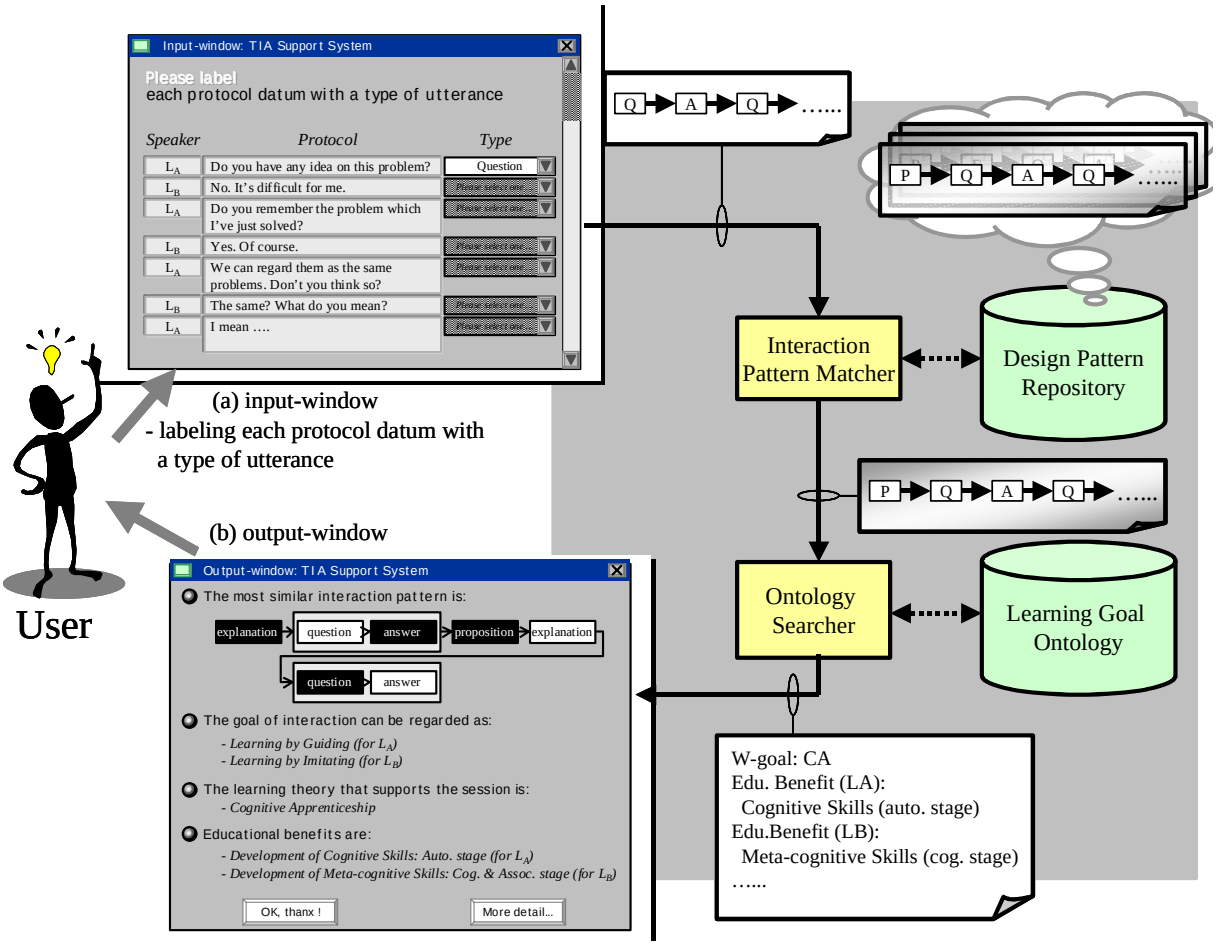

Fig.6 Overview of an Interaction Analyzing Support Tool: TIA Support Tool

theory. That is, the interaction-pattern characterizes the collaborative learning session that can be well-justified by a certain learning theory. The Interaction-Pattern Matcher searches the *repository* for the most similar interaction-pattern to the protocol data. Then, the Ontology Searcher searches the Learning Goal Ontology using the interaction-pattern as a cue to identify the followings: the goal of the interaction (*i.e.*, **Y<=I-goal**), the educational benefits expected for each learner (*i.e.*, **I-goal**), the common goal of the members of the group (*i.e.*, **W-goal**), and the type of collaborative learning occurred in the learning group (*i.e.*, **setting goal)**.

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 tool, we have been preparing the utterance types as vocabulary to represent the interaction process in order to abstract the essence of the interaction. First, we have picked up the vocabulary from learning theories for abstracting raw protocol data. Now, we have been elaborating it through some experiments. After that, we will represent interaction process among learners with the vocabulary, and construct the Interaction-Patterns.

5. Summary

We have been conducting a project aiming at developing various kinds of ID support tools for CSCL. In this paper, we described the ID process for CSCL, our approach to support it, and proposed the ID support environment with some repositories whose data are described by common vocabulary. We showed part of vocabulary and design patterns based on our Collaborative Learning Ontology as examples. Then we introduced an ID support tool using the repositories as an example. The TIA support tool 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. Our future work includes enriching each repository in the ID support environment for CSCL, and evaluating effectiveness of the environment and tools using the repositories.

References

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

[2] Bandura, A. ``Social Learning Theory", New York: General Learning Press (1971)

[3] Barros, B., & Verdejo, M.F. ``Analysing student interaction processes in order to improve collaboration. The DEGREE approach", IJAIED, 11 (2000) *to appear.*

[4] Bransford, J. D., Vye, N., Kinzer, C., & Risko, R. ``Teaching thinking and content knowledge: Toward an integrated approach", In. B. Jones & L. Idol (Eds.) Dimensions of thinking and cognitive instruction. Hillsdale NJ: Erlbaum. 381-413 (1990)

[5] Cognition and Technology Group at Vanderbilt. ``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. 244-273 (1992)

[6] Collins,A. ``Cognitive apprenticeship and instructional technology", In: Idol, L., & Jones,B.F. (Eds.) Educational values and cognitive instruction: Inplications for refoem., Hillsdale, N.J.: L. Erlbaum Associates, (1991)

[7] Endlsey, W.R. ``Peer tutorial instruction", Englewood Cliffs, NJ: Educational Technology (1980)

[8] Fitts,P.M. ``Perceptual-Motor Skill Learning", In: Melton,A.W. (Ed.), Categories of Human Learning, Now York: Academis Press. 243-285 (1964)

[9] Flavell, J. H. ``Metacognitive aspects of problem-solving", In L.B. Resnick (Ed.), The nature of intelligence. Hillsdale, NJ: Erlbaum. 231-235 (1976)

[10] Gagne,E.D. ``The Cognitive Psychology of School Learning", Scott, Foresman & Company (1985)

[11] Gersten, R., Woodward, J., & Darch,C. ``Direct instruction: A research-based approach to curriculum design and teaching", Exceptional Children, 53, 17-31 (1986)

[12] Ikeda, M., Hoppe, U., & Mizoguchi, R. ``Ontological issue of CSCL Systems Design", Proc. of AIED95, 234-249 (1995)

[13] Ikeda, M., Go, S., & Mizoguchi, R. ``Opportunistic Group Formation", Proc. of AIED97, 166-174 (1997)

[14] Inaba, A., Ikeda, M., Mizoguchi, R., & Toyoda, J. ``The Learning Goal Ontology for Collaborative Learning", http://www.ai.sanken.osaka-u.ac.jp/~inaba/LGOntology/ (2000)

[15] Inaba, A., Supnithi, T., Ikeda, M., Mizoguchi, R., & Toyoda, J. ``How Can We Form Effective Collaborative Learning Groups? -Theoretical justification of ``Opportunistic Group Formation" with ontological engineering", Proc. of ITS2000, 282-291 (2000)

[16] Inaba, A., Supnithi, T., Ikeda, M., Mizoguchi, R., & Toyoda, J. ``An Overview of Collaborative Learning Ontology", ECAI2000 Workshop on Analysis and Modelling of Collaborative Learning Interactions, 23-30 (2000)

[17] Inaba, A., Supnithi, T., Ikeda, M., Mizoguchi, R., & Toyoda, J. ``Is a Learning Theory Harmonious with Others?", Proc. of ICCE2000 (2000) *to appear.*

[18] Katz, A., O'Donnell, G., & Kay, H. ``An Approach to Analyzing the Role and Structure of Reflective Dialogue", IJAIED, 11, (2000), *to appear.*

[19] Lave, J. ``Cognition in practice", Cambridge University Press (1988)

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

[21] Mizoguchi, R., & Bourdeau, J. ``Using Ontological Engineering to Overcome Common AI-ED Problems", IJAIED, 11 (2000)

[22] Mizoguchi,R., Ikeda,M., & Sinitsa,K. ``Roles of Shared Ontology in AI-ED Research", Proc. of AIED97, 537-544 (1997)

[23] Muhlenbrock, M., & Hoppe, U. ``Computer Supported Interaction Analysis of Group Problem Solving", Proc. of CSCL99, 398-405 (1999)

[24] Piaget, J., & Inhelder, B. ``The Psychology of the Child", New York: Basic Books (1971)

[25] Resnick, M. ``Distributed Constructionism", Proc. of the International Conference on the Learning Science (1996)

[26] Rumelhart, D.E., & Norman, D.A. ``Accretion, Tuning, and Restructuring: Modes of Learning", In: Cotton, J.W., & Klatzky, R.L. (Eds.) Semantic factors in cognition. Hillsdale, N.J. : L. Erlbaum Associates., 37-53 (1978)

[27] Salomon, G. ``Distributed cognitions", Cambridge University Press (1993).

[28] Schoenfeld, A. ``Cognitive Science and Mathematics Education", Hillsdale, NJ: Erlbaum Assoc. (1987)

[29] Soller, A. ``Supporting Social Interaction in an Intelligent Collaborative Learning System", IJAIED, 12, (2001) to appear.

[30] Spiro, R. J., Coulson, R., L., Feltovich, P. J., & Anderson, D. K. ``Cognitive flexibility: Advanced knowledge acquisition ill-structured domains", Proc. of the Tenth Annual Conference of Cognitive Science Society, Erlbaum, Hillsdale, NJ, 375-383 (1988)

[31] Supnithi, T., Inaba, A., Ikeda, M., Toyoda, J., & Mizoguchi, R. ``Learning Goal Ontology Supported by Learning Theories for Opportunistic Group Formation", Proc. of AIED99 (1999)

[32] Vygotsky, L.S. ``The problem of the cultural development of the child", Journal of Genetic Psychology, 36, 414-434 (1929)

[33] Vygotsky, L.S. ``Mind in Society: The development of the higher psychological processes", Cambridge, MA: Harvard University Press (1930, Re-published 1978)