Models and Vocabulary to Represent Learner-to-Learner Interaction Process in Collaborative Learning

An Ontological Approach to Interaction Analysis

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Abstract: In this paper, we introduce an example of interaction patterns which are models of desired interaction process inspired by learning theories and vocabulary to represent the models. To evaluate collaborative learning session itself and/or educational benefits for learners, we should analyze interaction process, and capture what actually happens in the session. However, the interaction process is too complex to analyze for novice teachers or system designers. One of major causes of the difficulty is the lack of models and vocabulary to represent the process. So, we propose the vocabulary and the models of the interaction process described by the vocabulary.

Introduction

In order to design effective collaborative learning sessions, and analyze collaborative learning processes, it is necessary to describe and share the desired models of collaborative learning sessions, and to prepare common vocabulary to represent the models. As what we can rely on for design rationale of computer supported collaborative learning (CSCL) environments or criteria to evaluate educational benefits through collaborative learning sessions, there are many research findings on relationship between interaction and educational benefits, human socially learning process, and learning community. These research findings are called learning theories and people have considered their applications to the problems. But many of the learning theories are difficult for designers to understand what their intended collaborative learning sessions are, because the designers are not necessarily experts about the theories, and there is no common and solid system of concepts for collaborative learning among learning theories, system designs, and educational practices.

Based on the above observation, we have been adopting Ontological engineering technique to establish shared understanding about the model of collaborative learning sessions (Inaba, et al, 2000a, 2000b, 2001, 2002; Supnithi et al., 1999). By the help of ontology, we want to represent and store models of typical collaborative learning sessions inspired by the learning theories, and facilitate users' design and analysis of a collaborative learning session by referring to the models as the design rationale. The key to understanding CSCL lies in understanding the rich interaction between individuals (Dillenbourg, 1999). To evaluate a collaborative learning session itself and educational benefits for each learner getting through the session, we should analyze interaction process among learners, and capture what actually happens in the learning session. So, interaction analysis has been attracting attention of many researchers (Barros & Verdejo, 2000; Katz, et al., 2000; Muhlenbrock & Hoppe 1999; Okamoto, et al, 1995; Soller, 2001). However, the interaction process among learners is too complex to estimate educational benefits for each learner, and it is difficult for novice teachers or designers to analyze whether the processes progressed as they intended. One of the major causes of the difficulty is the lack of models and vocabulary to represent the interaction process. If users have the models and vocabulary to represent their desired interaction process, they can represent it explicitly, and share it with other teachers, designers, and even computers. Then, the computers will be able to support the process of interaction analysis.

The aim of our research includes constructing such models and vocabulary that represent learner- to-learner interaction process. To fulfill the aim, first, we prepare a prototype set of utterance-labels as the vocabulary to abstract protocol data during collaborative learning sessions. The labels are collected to represent interaction process in seven types of typical collaborative learning sessions. Second, we set the seven types of collaborative learning sessions based on our Collaborative learning ontology. Each group is designed according to a model of collaborative learning inspired by one of the learning theories. At the beginning of each session, we assign a role to each learner; and explain the role, learning goals, and intended interaction to the learners. We collect protocol data during the session to observe what utterance is occurred in each group. The group is top-down controlled, however, we do not control what utterance the learners say. So, the control is not obstacle to collect typical interaction process in the theory-based

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Table 1: Activities in collaborative learning

Behavior	Definition
Tutoring	To explain something he/she already knows to other learners
Passive learning	To listen something new from other learners
Guiding	To demonstrate something to other learners and guide the other's behavior
Imitating	To imitate other learners' behavior
Presentation	To explain the learner's thinking process, opinion, or strategy for problem solving
Reviewing	To compare and review other learners' opinions and self-thinking process
Advising	To diagnose problems and give some advice to other learners
Problem solving	To solve problems collaboratively

collaborative learning sessions, and to select utterance-labels. Next, we investigate whether the prototype labels are adequate or not to represent the protocol data during the collaborative learning sessions, and refine them. Forth, the refined labels are clustered, and we collect a set of vocabulary at an abstract level (we call the vocabulary "utterance-types") to characterize the session. Finally, we regard the protocol data as desired interaction processes in each learning theory, extract typical interaction processes from them, and model them as interaction patterns which are represented with the utterance-types. The interaction patterns work as reference models which represent typical interactions processes inspired by the learning theories. Using the utterance-labels, educational practitioners and system designers will be able to abstract learner-to-learner interaction process. By converting the sequence of utterance-labels into the sequence of utterance-types, it will help to abstract and capture the essence of the interaction process, and to measure similarity among interaction processes. And then, by comparing the interaction process with the interaction pattern, the computer will grasp characteristics of the collaborative learning session and help the users.

Vocabulary to Represent Interaction Process During Collaborative Learning: Utterance-Label

To prepare a set of utterance-labels which are used as a vocabulary to represent an interaction process, we adopt the procedure as follows;

- preparing prototype set of utterance-labels,
- collecting protocol data during collaborative learning sessions, and
- refining the prototype set through an investigation which asks intended users to tag each protocol datum with one of the labels in the prototype set.

There are different types of collaborative learning sessions. Every educational benefit that participants get through collaborative learning has its own desired interaction process. So, we need to prepare an appropriate set of utterance-labels which can represent the various kinds of collaborative learning processes and be distinguishable the differences among each kind of the interaction process. To enrich a variety of collaborative learning that can be represented with the utterance-labels, we collect the prototype set of the utterance-labels and protocol data to use for refining the prototype set based on multiple learning theories. We have been constructing Collaborative learning ontology which is a system of concepts to represent collaborative learning sessions (Inaba et al. 2000a; Supnithi et al. 1999), and we have proposed a group formation system for collaborative learning inspired by learning theories based on the ontology (Inaba et al. 2000b). In this research, we also rely on the learning theories as justification for design and analysis.

Prototype Set of Utterance-Labels as Vocabulary

We have been extracting learners' activities during a collaborative learning session in our ontology. [Table 1] shows the activities which are frequently observed in typical collaborative learning sessions. We prepare the prototype set of utterance-labels to represent interaction process based on the activities. That is, we suppose utterances which should appear when a learner performs the activities. And then, we collect utterance-labels which characterize the utterances. For example, in the learning theory "peer tutoring", there is a role "peer tutor" for a learner, and the learner who plays the role should perform an activity "tutoring". We can suppose that the learner gives some distinctive utterances to perform the tutoring activity, and the utterances are represented as utterance-labels like "teaching his/her own knowledge", "answering a question", and so on. [Figure 1] shows the prototype set of utterance-labels. A label is composed of three factors: *doing*, *whose*, and *what*. One example of the labels is "showing (*doing*) his/her (*whose*) troubles (*what*)", and another one is "asking (*doing*) other learners' (*whose*) strategy to solve a problem (*what*)". If the label means that someone gives an opinion, we need more information which represents an

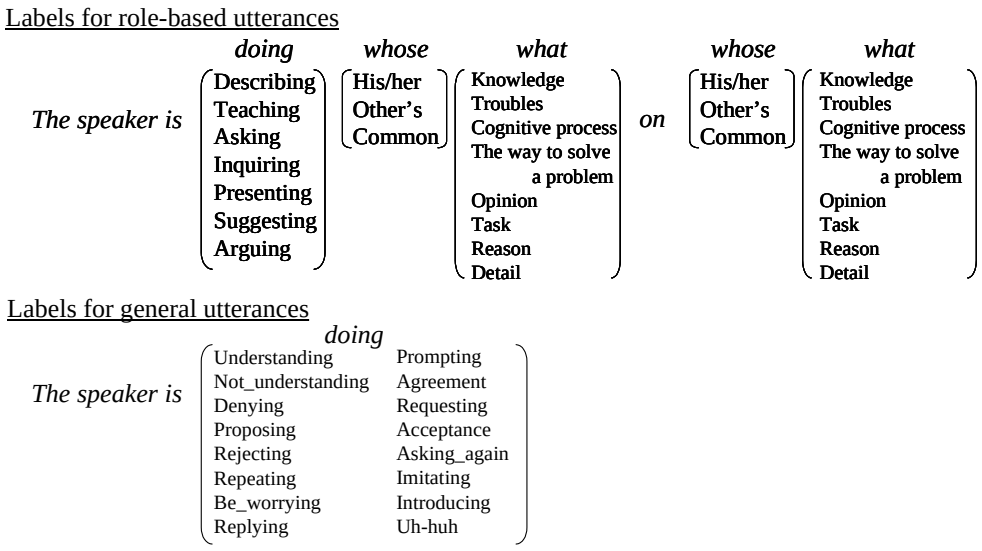

Figure 1: Prototype set of utterance-labels

object of the opinion. The object is also represented as a set of factors: *whose* and *what*. One example of the labels is "offering (*doing*) his/her (*whose*) opinions (*what*) on common (*whose*) problems (*what*)", and another one is "offering (*doing*) his/her (*whose*) opinions (*what*) on other learners' (*whose*) opinions (*what*)".

During collaborative learning, learners speak something not only based on their roles (role-based utterances), but also to activate their interaction (general utterances); for example, expressing agreement, asking again, promoting interaction, and so on. The label-set easy to use should represent not only the role-based utterances but also frequently observed general utterances. We collect the labels to cover the two types of utterances. The general utterances are represented as single gerund like prompting, asking again, and so on.

Collecting Protocol Data during Collaborative Learning inspired by Learning Theories

We set the seven types of collaborative learning sessions based on our Collaborative learning ontology. Each group is designed according to a model of inspired by one of the learning theories: Anchored Instruction (Cognition & Technology Group at Vanderbilt, 1992), Cognitive Apprenticeship (Collins, 1991), Peer Tutoring (Endlsey, 1980), Cognitive Constructivism (Piaget & Inhelder 1971), LPP (Lave & Wenger, 1991), Cognitive Flexibility (Spiro, et al., 1988), and Distributed Cognition (Salomon, 1993). We have been constructing Learning Goal Ontology, which is a part of the collaborative learning Ontology, and the Learning Goal Ontology clarifies learning goals, which are expected to learners get through a collaborative learning session, and relationships among a learner's personal development and interaction process with the other learners (Inaba, et al, 2000a, 2000b). The ontology relies on learning theories as the rationale. We formed the learning groups based on the ontology, and collected the protocol data during the session.

[Table 2] shows roles and tasks in the seven types of collaborative learning settings. We set the roles for each setting based on our Learning Goal Ontology. As an example, [Figure 2] shows a setting inspired by learning theory "Peer Tutoring" described with our ontology. The ontology describes roles for each learner, number of learners who play a role, activity for each role, learning goals which are goals for the whole group, goals for interaction, and goals for a learner's personal development, and so on. The tasks are selected for ease of performing each role which appears in each setting. For example, in the setting inspired by "Peer Tutoring", there are two roles; peer tutor and peer tutee, and main activity is knowledge-transfer from peer tutor to peer tutee. So, we select for the setting the task "to teach table manners" which has many rules and leaves little room for discussion. As another example, in the setting inspired by "Cognitive Apprenticeship", there are two roles; a master and an apprentice, and main activity is a demonstration of problem solving by the master, imitation of it by apprentice, and guiding the imitation by master. So, we select the task "to solve a geometric problem with an auxiliary line" which requires a cognitive skill to find out where we need to draw an auxiliary line to the original diagram. At the beginning of each session, we assign a role to each learner; and explain the role, learning goals, and intended interaction in the session. We collect protocol data during the session to observe what utterance is occurred in each group. The group is top-down controlled, however, we do not control what utterance the learners say. So, the control is not obstacle to collect typical interaction process in theory-based collaborative learning sessions. The learners learn collaboratively in a face-to-face environment, and

Table 2: Roles and tasks in the learning settings

	Setting	
Learning Theory	Roles (the number of persons)	Task
Peer tutoring	Peer tutor (2), Peer tutee (1)	Table manners
Cognitive Apprenticeship	Master (2), Apprentice (1)	A geometric problem with an auxiliary line
Anchored Instruction	Problem holder (1), Anchored Instructor (2)	A problem of probability
Cognitive Constructivism	Full participant (3)	A problem of weighting with a balance
Distributed Cognition	Full participant (4)	A gender issue
Cognitive Flexibility	Panelist (2), Audience (1)	How to pass the entrance exam. of the univ.
LPP	Full participant (3), Peripheral participant(1)	A problem of weighting with a balance

all of the sessions are recorded by a video camera and an IC recorder. We collect protocol data and confirm the learners interact with other learners just as we designed. The total number of utterances is 1,242.

Refining the Prototype Set through an Investigation

The prototype set of utterance-label has redundancy. It may include labels which will not be used or these difficult to distinguish each other. To prepare label-set easy to use, we should refine the prototype label-set. To refine it, we collect data to investigate what labels are needed to tag utterances observed during the seven types of typical collaborative learning. We show the protocol data (1,242 utterances) on the web, and ask intended eleven users (e.g., CSCL designers and educational practitioners) to tag each protocol datum with one of the prototype utterance-labels. If the user does not find an appropriate label in the prototype set for an utterance, the user is asked to input a new label into the input box for free words.

The result of the investigation shows the prototype label-set is adequate to represent the seven types of typical collaborative learning; there was no input as a new label. Moreover we made a little modification for the prototype label-set based on the result. First, we deleted the label “uh-huh (giving response)” from the prototype set. The label is used very frequently, and it is frequently used for the same utterance labeled with “understanding” or “prompting (other participant’s utterance)”. This shows that the label “uh-huh” is not appropriate and its meaning is ambiguous: it includes the meaning of the labels “understanding” and “prompting”. Similarly, the label “replying” is deleted from the label-set, because it is frequently used for the same utterance which labeled with “agreement” or “denying”. The label “inquiring” is deleted from the label-set, because it is frequently used for the same utterance labeled by “asking”. There are labels that no user used. We left the labels in the label-set, because the labels were redundant, but did not seem to confuse the users for tagging protocol data.

Characterizing Interaction Process: Utterance-Types and Interaction Patterns

We prepare two kinds of vocabularies to represent interaction process: utterance-LABELS we described in previous section and utterance-TYPES we describe here. To ease labeling to each utterance, we need a vocabulary at a concrete level. On the other hand, to ease characterizing learning sessions, we need a vocabulary at an abstract level. We satisfy these contradictory requirements by clustering terms.

Utterance-Types: Vocabulary at an Abstract Level

We cluster the utterance-labels with a hierarchical cluster analysis method. First, we delete the labels, which are used only once or twice, as noise data. Then, we set each value of properties as follows;

Case: utterance-label {93}
Variable name: utterance {1,242}
Variable: number of subjects to select an utterance-label
Distance: Squared Euclidean Distance
Similarity Measuring Method: Furthest Neighbor Method

To avoid that similarity of the labels depends on the frequency of usage of the labels, we normalized the absolute value of vectors to calculate the distance. [Figure 3] shows a part of the dendrogram as a result of the analysis. Using the hierarchical cluster analysis method, cases with high similarity are adjacent. For example, the dendrogram shows the utterance-label “teaching his/her knowledge” is very similar to the label “telling common knowledge”, because these two labels are adjacent and form a cluster. Then, the cluster forms a new cluster with the label “telling his/her knowledge”. The numbers in the figure mean the order to be formed a cluster.

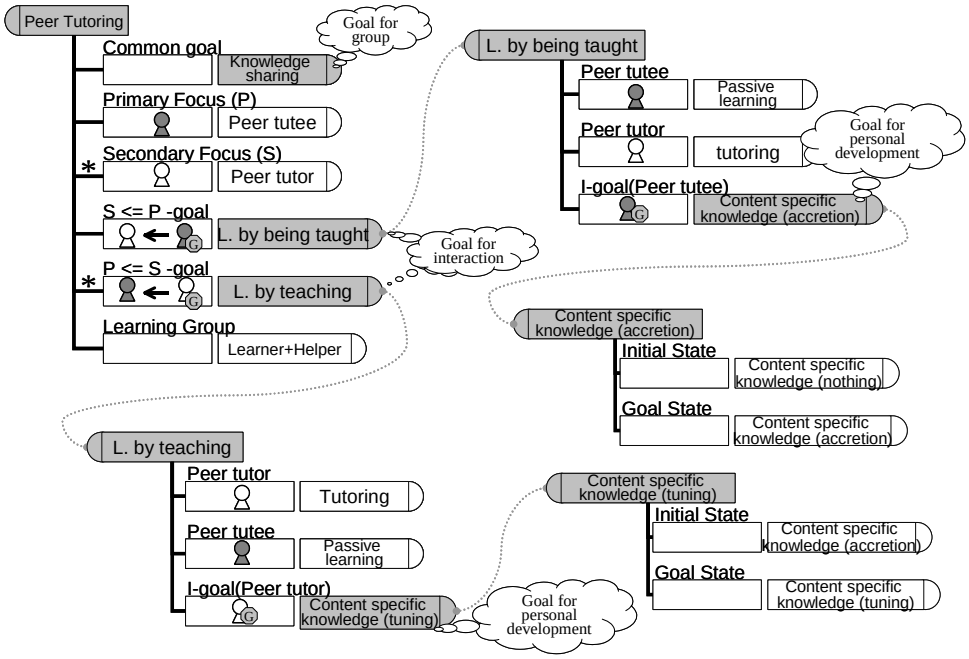

Figure 2: **A setting inspired by the theory "Peer Tutoring"**

By clustering the utterance-labels, we can abstract interaction process at an arbitrary level as the need arises, while we keep usability of the utterance-labels to tag each protocol datum. If the set of utterance-labels often change depending on the purpose of analysis, for example, users are required to tag protocol data again with another set of utterance-labels whenever the users want to know something new, the users feel difficulty to use them, and it is very complex and time-consuming. We do clustering the vocabulary once, and then provide for users the vocabulary at the most concrete level of the cluster to tag raw protocol data; we use the vocabulary at an abstract level of the cluster to characterize interaction processes. We call the vocabulary at an abstract level utterance-type. [Table 3] shows examples of the utterance-types. Each utterance-type shows a cluster of utterance-labels, and the names of the utterance-types are arbitrary. So, we set the names to abstract and represent the meanings of the utterance-labels which compose the cluster. In our vocabulary, the relations among utterances, e.g., whether an opinion-A after another opinion-B means agreement to B or not, are represented by utterance-labels. So, converting the utterance-labels into the utterance- types is not influenced by the order of utterance-labels. The level of abstraction should be defined to distinguish and characterize each type of collaborative learning session by the utterance-types. Now, we have set utterance-types adequate to represent and be distinguishable the seven types of interaction patterns, however, we have not conceptualized other utterance-types yet.

Interaction Patterns: Models of Interaction Process during Collaborative Learning

We construct several types of interaction patterns. Each interaction pattern is a model of typical interaction process which is frequently observed in collaborative learning session. Every learning goal has its desired interaction processes: if a specific interaction process appears, we can expect for the learners to achieve a specific learning goal. In our research, we extract learners' roles, activities for the roles, a prototype set of labels for role-based utterances, and distinctive interaction processes from the learning theories based on our ontology. And then, we collect protocol data in seven types of theory-based collaborative learning sessions. Using the protocol data, we verify, refine, and clarify the utterance-labels and interaction processes to share them with educational practitioners, system designers, and even computers. Each interaction pattern shows desired interaction process which is described in one of the learning theories. In the learning theory, educational benefits each learner gets through the interaction are described. So, we will be able to infer whether the learner achieves a specific learning goal or not by comparing the learner-to-learner interaction process with the interaction patterns.

To construct interaction patterns, first, we represent protocol data during collaborative learning sessions with utterance-types. As we described in the previous section, we collect protocol data and ask intended users (CSCL designers and educational practitioners) to tag the protocol with utterance-labels through the investigation. We represent the interaction processes as sequences of utterance-labels, and convert the utterance-labels into more

Table 3: Utterance-types in collaborative learning

Utterance-types	
Knowledge transfer	Arguing one's position and/or opinions
Teaching a way to solve a problem	Request to show someone's opinions
Showing a way to solve a problem	Request to compare an opinion with the others
Request to show a way to solve a problem	Request more detail on another utterance
Externalizing one's trouble	Showing details
Diagnosing a trouble	Prompting
Asking other learners about their troubles	Agreement
Showing their troubles and/or tasks	Understanding

abstract utterance-types. Then, we get sequences of utterance-types which represent seven types of interaction processes in theory-based model of collaborative learning. We set criteria to extract distinctive interaction processes from the sequences of utterance-types as follows; the process in which most users use similar utterance-labels (they are converted to the same utterance-type), the process which is frequently observed in the session, and the process which represents the characteristics of the session well.

The reason why we convert the utterance-labels into the utterance-types is to absorb uneven usage of the labels among users. It is possible that each user tags different labels for the same utterance. Also even the same user often uses different labels for very similar utterances. Usually, the meanings of the labels are very similar, but many users tend to distinguish them by the labels. If the label-set has no capacity to distinguish them, the users feel difficulty in using the label-set. On the other hand, if we construct a label-set which has enough capacity for representing utterances, the label-set becomes large and there are many labels to represent similar meanings. It is difficult to capture what types of interaction have occurred, characterize a learning session, and infer similarity of several interaction processes using the large and concrete label-set. To do that, we need vocabulary at more abstract level. This is why we prepare two types of vocabularies: utterance-labels and utterance-types. The utterance-labels are used by users to tag protocol data; the utterance-types, which are more abstract vocabulary than the utterance-labels, are used to capture essences of the interaction process and characterize the session.

An Example of Interaction Patterns inspired by a Learning Theory

[Figure 4] shows typical interaction process which is frequently observed in Cognitive Apprenticeship (Collins, 1991) type of collaborative learning session as an example of the interaction patterns. An interaction pattern is represented as utterance-types (represented as nodes) and possible transitions (represented as arrows) among the

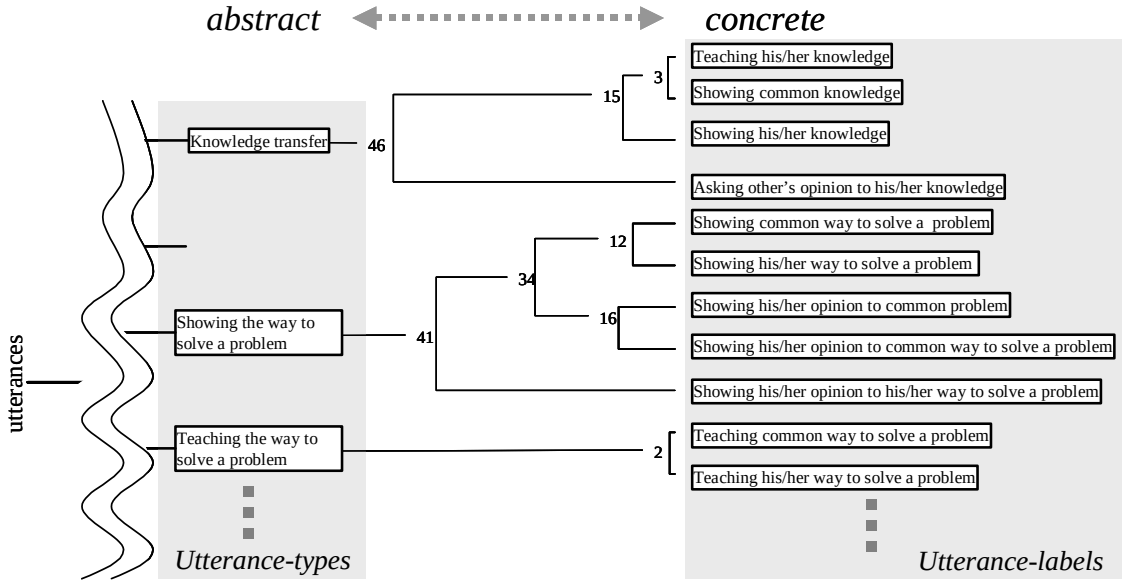

Figure 3: A part of the dendrogram as a result of the cluster analysis

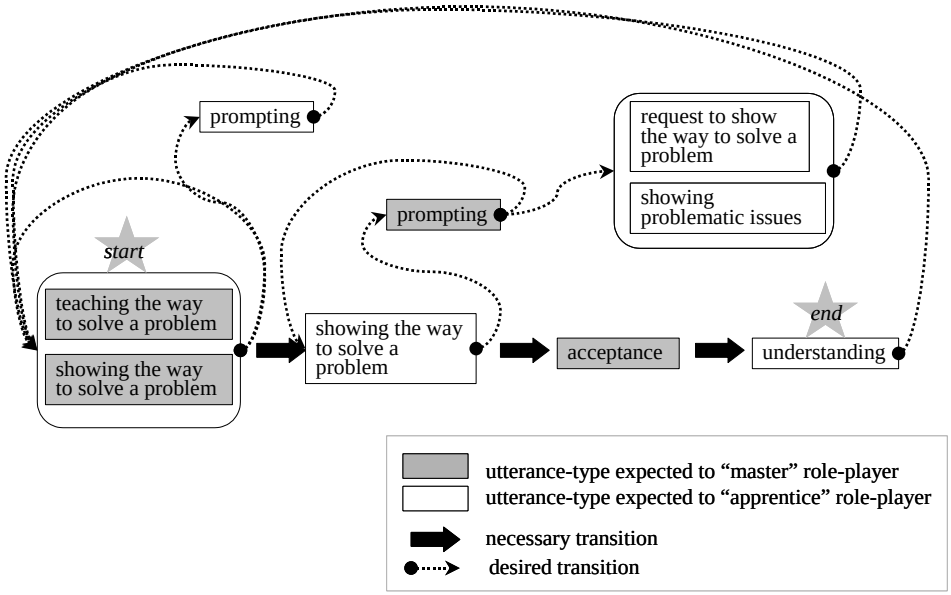

Figure 4: An example of Interaction Pattern: cognitive apprenticeship

utterance-types. There will be four types of transitions among the utterance-types: desired transitions, necessary transitions, wrong transitions, and the others. At present, we construct interaction patterns to represent the necessary transitions and desired transitions, and in future, the interaction pattern will also represent wrong transitions among the utterance-types for a specific learning goal. The theory of Cognitive Apprenticeship describes the learning process in which a novice learner acquires new knowledge and skills with helps by skilled learners. There are two roles for learners: a master and an apprentice. The master means the skilled learner and the apprentice means the novice learner. First the learner who plays the master-role demonstrates his/her problem-solving process for the apprentice. The learner who plays the apprentice-role observes the process, and then he/she tries to solve a problem his/herself by imitating the process in which the master did. The master guides the process the apprentice solves the problem. In [Figure 4], at the beginning of the learning session, the master tells to the apprentice something like "teaching the way to solve a problem" or "showing the way to solve a problem". Next, the apprentice tries to solve a problem his/herself. The utterances are represented as the type "showing the way to solve a problem". And then, if the apprentice performs well, the master shows "acceptance" for the apprentice, and the session ends with the apprentice's "understanding". These are essential flows of the learning session of Cognitive Apprenticeship. This type of learning session is characterized as follows: there is a turn taking who tells about the way to solve the problem; first, the master tells it, next the apprentice tells it.

Also, there are some utterance-types as desired transitions. The desired transitions mean that; even if the transitions do not appear in the learning session, we can say the session is successful; if the transition do appear, we can expect the learners can get more educational benefits in the session. In the Cognitive Apprenticeship type of learning session, the master may repeat some utterances classified into "teaching the way to solve a problem" or "showing the way to solve a problem", the apprentice may say something classified into "prompting" like "ok" and "oh!". Moreover, the apprentice says something like "request to show the way to solve a problem" and "showing problematic issues".

Conclusion

We described the need to have models and a vocabulary to represent learner-to- learner interaction process during collaborative learning. We proposed two types of vocabularies to represent learners' raw protocol data and characterize the learning session. And then we also introduced interaction patterns which are models of desired interaction process inspired by learning theories. By representing typical interaction process explicitly like this, it becomes possible to compare real interaction process with typical interaction process, and help users estimate educational benefits for the learners.

We have been constructing an interaction analysis support system which helps users analyze complex interaction process among learners (Inaba, et al, 2001, 2002). The system provides the utterance-labels for users to tag

protocol data, and convert them into the utterance-types. And then the system analyzes the interaction process by comparing it with interaction patterns. The clusters of terms and interaction patterns will be useful to reduce users difficulty in interaction analysis, to share collaborative learning model explicitly among users, and to enable computer systems to help the process. At this stage, we rely on learning theories to construct interaction patterns and pick up utterance-labels. For future work, we plan to extend the system to embed a module that users can store new interaction patterns to the system. By this extension, the users use their best practice as typical collaborative learning patterns. Moreover, we will construct a collaborative learning support system in which learners select utterance-labels or use sentence-openers, and the system identifies the state of collaborative learning and advises the learners on their learning.

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