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A Design of Interaction Model among Pedagogical Agents in Collaborative Teaching Process

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Abstract. The aim of this study is to design and develop an interaction model to perform the collaborative teaching process among pedagogical agents. A pedagogical agent has a role in a situation of the teaching process. However, the role is not fixed, but dynamically changed according to the learner's understanding. So, in this paper, we have analyzed the collaborative teaching process between one learner and two teachers for the subject of multiple fraction in elementary school, and extracted communication performatives and protocols for interaction required in this process as an interaction model. Moreover, we describe an example of a collaborative teaching process by using the extracted communication performatives and protocols.

1. Introduction

The education and learning tasks are included as one of the application fields of agent technology [5]. The Intelligent Learning Environments (ILEs) has a wide variety of research fields such as knowledge representation of domain and expert systems, student modeling, teaching strategy, system architecture and teaching paradigm [10], [15]. So, we know that the development of the effective ILEs needs many costs, much time and various resources. The available methodology for solving the problem is to introduce component architecture which implements a component as an agent. This architecture which allows the addition and removal of components could support the development of flexible ILEs.

On the other hand, many approaches to support a learner or group learners in the learning processes are proposed in the field of ILEs [3],[17].

In recent years, there are many ILE systems which incorporate the agents such as Pedagogical Agents (PAs) and Peer Agents, as a means to realize the teaching, coaching and supporting function in developing the learning environment. The examples of the learning environments using agents are the following:

- An agent supports the learning activity of the learner in a distributed collaborative learning [2], [9].
- An agent plays a roll in pseudo student in a collaborative learning environment [4], [11].
- Multiple tutor agents which have different knowledge support a learner through communication, cooperation, competition [8].

Various problem solvings through collaboration among the agents are acted in agent-based learning environments. So, such learning environments desire to develop smooth interaction among agents. Therefore, a flexible interaction model to request, collaborate, negotiate among them must be proposed.

Considerating the background of our study as mentioned above, the aim of this study tries to realize an interaction model, where multiple agents which have different teaching strategy collaboratively design a teaching plan and act a teaching behavior. In this paper, we analyze and classify the collaborative tasks among the PAs in the teaching process. Moreover, we examine and propose communication performatives and protocols for interaction required in their tasks.

2. What is advantage in learning environment included in pedagogical agents?

It is very important for us to present a design view to construct an interaction model. So, in the first place, we consider advantage in agents-based learning environment. The learning environment, in which multiple agents join, offers learners more support functions than single agent learning environment. The examples of advantage are as following:

< To learner >

- Manysided understanding for subject matter
  A learner can learn plural ways of solving or explanation.
- Observational learning
  A learner can learn from interaction among agents to solve the problem.

< To Pedagogical Agent >

- Learning function
  PA can learn teaching strategy and skill from other PA's behavior [5].

We have discovered unique features of multiple PA learning environments such as manysided understanding and observational learning. Therefore, we need to consider an interaction technique among the PAs to control intentionally learning process by the PAs.

3. Interaction among pedagogical agents in collaborative teaching process

Agent Communication Language (ACL) is to exchange messages between agents [6], [7], [8]. The key point to realize smooth interaction is the design of perfomative and protocol, in which the task and the degree of abstract are very important. In this section, we discuss the interaction among pedagogical agents in collaborative teaching process. The domain we discuss is multiple fraction in the elementary school.

3.1. Interaction Structure in collaborative teaching process

Dialogue is composed of some utterance more than two peoples. When a people speaks something, he/she has a dialogue goal. Moreover, there is the logical relationship between utterances. Some utterances construct an unit (we call **an unit dialogue goal**) which achieves the dialogue goal. So, each utterance is accounted to be an act of a speaker to achieve an unit dialogue goal or a dialogue goal.

We apply this view of dialogue structure to interaction in the teaching and learning process. The dialogue goal corresponds to learning goal. The unit dialogue goal corresponds to a subgoal such as "solve a problem" and "answer a learner's question" to achieve the learning goal. Moreover, the learner and teacher consider an utterance such as "question" or "explanation" to achieve the unit dialogue goal as an act.

Fig. 1. shows an interaction structure of PAs. The interaction structure in the learning environment (one learner and one teacher) consists of only one hierarchy. But, in the learning environment (one learner and some PAs), the interaction structure consist of two hierarchy (Interaction stage to diagnose the student's understanding state or decide the next teaching content amongPAs, Interaction stage between the student and the PAs).

So, the interaction stage among PAs is meta-interaction stage for the interaction

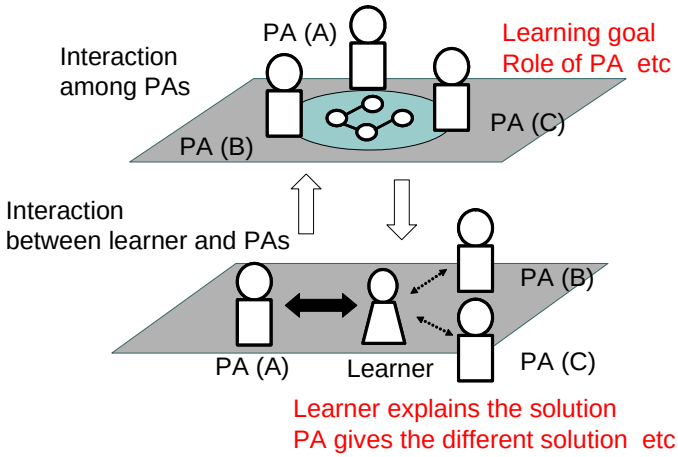


Fig. 1. Two interaction structures among PAs and a learner in collaborative teaching process

stage between the student and the PAs.

The Collaboration in teaching task means the collaboration among PAs in a narrow sense. Also, the collaboration to execute the learning process between the student and the PAs means the collaboration in a broad sense. In case the PAs collaboratively decide effective teaching process, the collaboration in each stage is needed.

3.2. Extraction of dialogue goals and communication performatives

In this study, we try to extract the dialogue goals, communication performatives and protocols from the viewpoint of dialogue analysis.

1. The method for analyzing instruction and communication are proposed in research on classroom instruction. The unit of analysis and the category of instructional analysis are also proposed. In research on ILE, the method for arranging knowledge about learning strategy and goal is proposed. Moreover, Austin and Searle systematically arranged human's speech acts and produced "Speech Act Theory" [1], [14]. We extract the dialogue goal and communication goal in teaching task by the reference of these researches.

2. We have recorded the interaction between one learner and two teachers in teaching and learning process. The subject is multiple fraction in

elementary school. We put the performative label on the each utterance, referring to illocutionary acts in the Speech Act Theory.

Table 1. Examples of communication performatives in collaborative teaching process

Question	Performatives which request answer to other PAs or a learner	
	question	to show the question to other PAs or a learner
	confirmation	to confirm whether other PA or a learner understand or not
	shakeable-question	to show the question to get the learning effect by giving the opportunity of reconsideration
	digging-question	to show the question to get the learning effect by deepening a learner's response
Learning	Performatives in learning process	
	showing	to show a problem
	answer	to show an answer of the problem
Request	Performatives to request some behavior to other PAs or a learner	
	request	to request a behavior to other PAs or a learner
	information-request	to request some information to solve a problem to a learner
	opinion-request	to request something opinion for utterance to other PAs
	braking-in	to ask other PAs for listening my opinion by interrupting the learning session
	indication	to indicate some behavior to other PAs or a learner
Opinion	Performatives which show the opinion to other PAs or a learner	
	opinion	to show the opinion to other PAs or a learner
	proposal	to show a proposal for the problem
	another-proposal	to show another proposal for the problem
	expectation	to show an opinion which the learner might make
	advise	to show an utterance which helps the learner
	explanation	to show an utterance to explain for other PAs or a learner

Response	Performatives which respond to the utterance of other PAs or a learner	
	response	to show a response for the question
	asking-back	to confirm the question which the utterance of other PAs or a learner can't understand
	sympathy	to show a response to humor other PAs or a learner
	acceptance	to accept the utterance of other PA or a learner
	refusal	to refuse the utterance of other PA or a learner
	agree	to show the agreement of opinion
	disagree	to show the disagreement of opinion
	understanding	to understand the implication or idea of the utterance
	lack-of-understanding	to not understand the implication or idea of the utterance
	judghment	to criticize the mistake of the utterance
	attention	to show the attension to the learner
	no-response	to not respond to the received message

Table 2. Examples of unit dialogue goal in collaborative teaching process

Among PAs	Before learning session	Protocol for correcting the state of learner's understanding
		(2) Protocol for selecting learning goal
		(3) Protocol for selecting problem
		(4) Protocol for deciding how to forward learning session
		(5) Protocol for role decision
	During learning session	(1) Protocol for role change
		(2) Protocol for requesting advice to other PA
		(3) Protocol for making advice
		(4) Protocol for reconsidering how to forward learning session
		(5) Protocol for correcting the opinion for problem
Between Learner AndPAs		(1) Protocol for showing problem
		(2) Protocol for settling learner's question
		(3) Protocol for requesting different answer to learner
		(4) Protocol for putting together learned content

From the above (1) and (2), we extracted illocutionary act as communication perfomative. We categorize the extracted communication perfomative into five classes (question, learning, opinion, request, and response). **Table 1.** shows the examples of communication performatives.

We gathered some utterances in the interaction and extracted unit dialogue goals from the utterance lists. We categorized the unit dialogue goals into two classes (between PA and learner, among PAs). Moreover, we classified them into two classes (before starting session, during session). **Table 2.** shows the examples of the unit dialogue goal between a learner and PAs and among PAs.

3.3. Communication Protocols in collaborative teaching process

The communication performatives and the unit dialogue goals are extracted from the interaction analysis in the experiment. We express the process by the list of communication performatives with a state chart, and define it as a communication protocol. There are two scenes among PAs. One is collaboration to decide the teaching process and the other is to execute it.

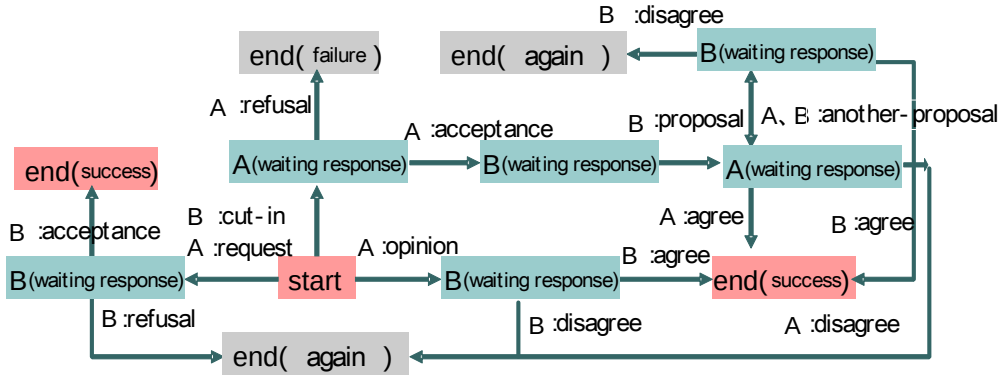
We call these two communication protocol as "**collaboration protocol**". In this unit dialogue goal, question is used to the both of two teaching processes. Below are the examples of the collaboration protocol in each teaching process.

[Example of collaboration protocol among PAs
about deciding teaching process]

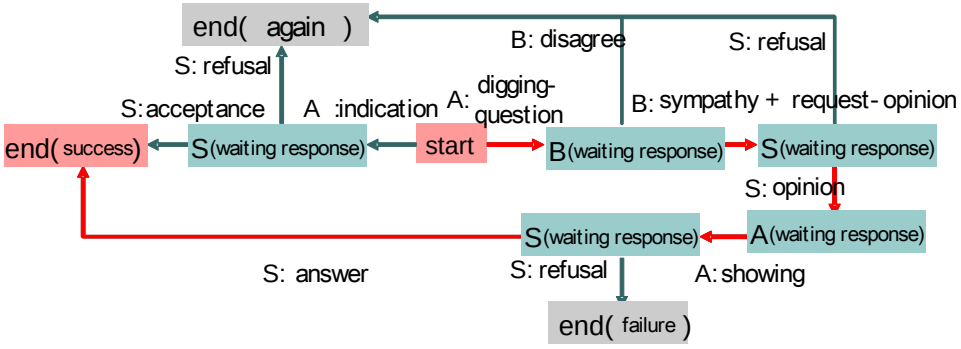
< Protocol for role change >

1. In case A agent which has the initiative acts "request", it waits the reaction whether B agent performs "acceptance" or "refusal". If it acts "acceptance", this protocol achieves a goal (Success). If it acts "refusal", the request is rejected and the protocol starts from scratch.
2.
3. In case A agent which has the initiative acts "opinion", it waits the reaction whether B agent performs "agree" or "disagree". If it acts "agree", this protocol achieves a goal (Success). If it acts "disagree", the request is rejected and the protocol starts from scratch.
4.
5. In case B agent which don't have the initiative acts "cut-in", it waits the reaction whether A agent performs "acceptance" or "refusal". If it acts "refusal", this protocol can't achieve a goal (Failure). If it acts "acceptance", B agent acts "proposal". Then, it waits the reaction whether A agent performs "agree" or "another-proposal". If A agent acts "agree", this protocol achieves a goal (Success). If it acts "another-proposal", it waits the reaction whether B agent performs "agree" or "disagree". If it acts "agree", this protocol achieves a goal (Success). If it

acts “disagree”, this protocol the request is rejected and the protocol starts from scratch.



Protocol for role change
(collaboration protocol among PAs about deciding teaching process)



Protocol for request different answer to learner
(collaboration protocol between learner and PAs about excecuting teaching process)

Fig. 2. Examples of collaboration protocol between PAs and learner

[Example of collaboration protocol between learner and PAs about executing teaching process]

< Protocol for requesting different answer to learner >

1. In case A agent acts “digging-question, it waits the reaction whether B agent performs “disagree” or “agree + request-opinion”. If it acts “disagree”, the protocol starts from scratch. If it acts “agree + request-opinion”, it waits the reaction whether S learner performs “refusal” or

"opinion". If it acts "refusal", the protocol starts from scratch. If it acts "opinion", it waits the reaction with which A agent acts "showing". Moreover, it waits the reaction whether S learner performs "refusal" or "answer". If it acts "refusal", this protocol can't achieve a goal (Failure). If it acts "answer", this protocol achieves a goal (Success).

2.

3. In case A agent acts "indication", it waits the reaction whether S learner performs "refusal" or "acceptance". If it acts "refusal", this protocol starts from scratch. If acts is "acceptance", this protocol achieves a goal (Success).

[Problem 1] $\frac{5}{6}+\frac{5}{7}+\frac{1}{6}-\frac{1}{7}$

$=\frac{35}{42}+\frac{35}{42}+\frac{7}{42}-\frac{6}{42}$

$=\frac{71}{42}$

[Problem 2] $\frac{3}{46}+\frac{1}{4}+\frac{43}{46}+\frac{1}{2}$

$=\frac{6}{92}+\frac{23}{92}+\frac{86}{92}+\frac{46}{92}$

$=\frac{161}{42}$

$=\frac{7}{4}$

Fig. 3. Problems of multiple fraction and answers of a

4. Example of interaction among agents

In this section, we describe an example of an interaction process in the teaching task by using the extracted communication performatives and protocols.

The domain in the example is multiple fraction. The two PAs are embedded in the learning environment. One is "Fraction Solving Tutor" which has solving rules to solve the multiple fraction. It supports the level of solving rules in the multiple fraction. The other is "Strategy Tutor" which has solving strategies about the multiple fraction. It supports the level of solving strategies in the multiple fraction. These two PAs design and execute the teaching plan with collaboration.

We use to extend a methodology for the Agent-Oriented Programming (Agent-0) advocated by Shoham for the representation of the agent included communication performative and protocol [16]. Agent-0 is a programming language to control by the mental state (working memory) and commitment rules which alter the mental state. In this study, we need to a framework to process the messages and the protocols and

manage the situation. Therefore, we introduce a blackboard model to the working memory to hold the mental state. Moreover, we classify the working memory into two area (one is the communication management part, the other is the problem solving part). We explain the collaborative interaction process between PAs, Fraction Solving Tutor and Strategy Tutor, which has the agent model. Now, the [Problem 1] shown in figure4 is given to a learner. The student solves the problem by using "whole common denominator strategy".
The student mistakes the common denominator method for 5/7. With the result that the learner mistakes the answer (71/42). The Fraction Solving Tutor recognizes the error of common denominator and holds it to mental state. The Strategy Tutor recognizes the "whole common denominator strategy" and holds it to mental state.

Then, the Strategy Tutor starts the "Protocol for making an advice" and considers the tactics and contents. The Fraction Solving Tutor proposes the advice about the error of common dominator. The Strategy Tutor agrees to the Fraction Solving Tutor. Because, it recognizes the "whole common denominator strategy", but can't understand the factor why the learner selects the strategy. The Fraction Solving Tutor gives an advice for the error to the learner. The learner gives another answer.

When the learner finished the [Problem 1], the Strategy Tutor starts "Protocol for role change" to understand how the learner selects the solving strategy. The Fraction Solving Tutor accepts the request of the Strategy Tutor. Moreover, starting "Protocol for selecting problem", the agents discuss the next problem. The Strategy Tutor proposes the problem which can recognize how to select the solving strategy. The Fraction Solving Tutor agrees to the proposal. As a result, the [Problem 2] shown in **Fig. 4.** is given to the learner and the Strategy Tutor has the initiative. The leaner solves the problem by using the same "whole common denominator strategy". The Strategy Tutor starts the "Protocol for making advice" and considers the tactics and contents. The Strategy Tutor knows that [Problem 2] is not a subtraction, and the solution with the "whole common denominator strategy" is too cost to put into practice. So, it proposes to the advice of "exchanging the order of the term strategy". The Fraction Solving Tutor agrees to its proposal, as the learner doesn't have a mistake at solving rule level. The Strategy Tutor starts the "Protocol for requesting different answer to learner" and gives a digging-question to the learner. The Fraction Solving Tutor requests a something opinion to the learner with collaborating the Strategy Tutor. The learner explains another strategy (to calculate, on ahead, the term which is same denominator) and makes the solution by using the new strategy.

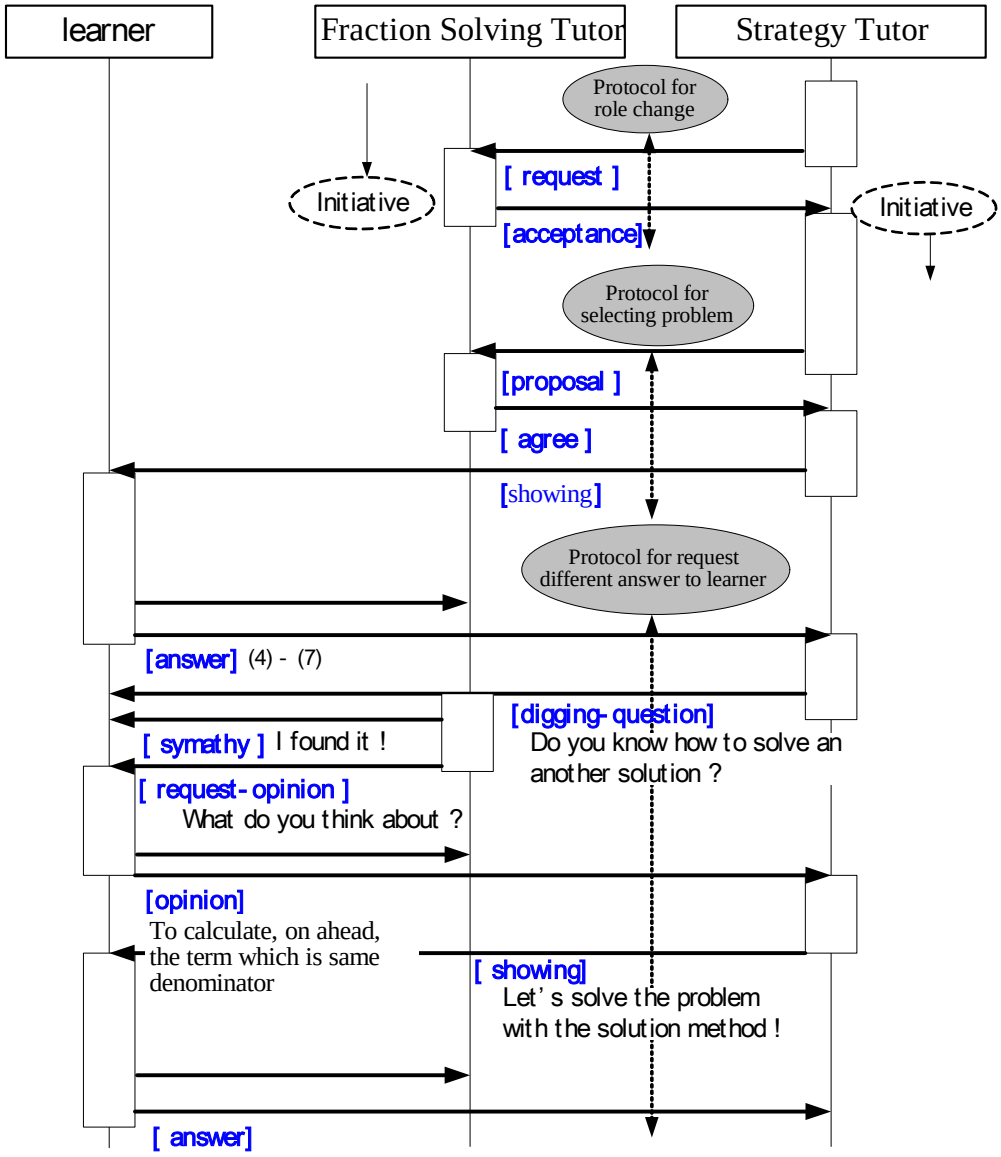


Fig. 4. An example of an interaction flow between PAs and learner

This is an example of an interaction process among PAs. Collaborating effectively among PAs, the learning environment is able to give more forceful interaction process to the learner. As a result, we expect that the learning effect increases more as compared with traditional ILEs.

5. Conclusions

In this paper, we analyzed and classified the collaborative tasks among the PAs in the teaching process. Moreover, we examined and proposed communication performatives and protocols for interaction required in teaching tasks. We think that these communication peformatives and protocols could use for other procedural problem solving domain.

As a next step, we try to implement this learning environment. Moreover, we need to consider an interaction model among PAs for the subject included the different field.

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