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Learning by Teaching Support Environment based on Teaching Assistant Activities with Teacher Agent

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Abstract: A learning environment where human learners learn by teaching computer agents generally has some advantages for their effective learning. One of the expected advantages is the learners can be aware of the related knowledge and the strategy of problem solving. However some human learners cannot succeed in teaching the agents as a learner even if these learners can completely resolve the problems. It is because these learners cannot diagnose the understanding level of the agents. Even if these learners can teach the answer of the problems, they cannot identify the causes of the agents' mistakes and lead them to the correct solution. In this paper, to support their learning by teaching, we propose a new learning environment where human learners learn by teaching as a teaching assistant. In this environment, these learners can receive some assistance from the teacher agent. The teacher agent supports the learners in diagnosing the causes of mistakes based on the related knowledge and the strategy of the problem solving, when the learners become stuck. Our preliminary evaluation shows the advantage to enable learners to be aware of the related knowledge and strategy.

Keywords: Learning by teaching, teacher agent, meta-cognition, learning environment

1. Introduction

The effect of "Learning by Teaching" was discussed in (S. Ohlsson (1996)) and (R. S. Siegler (2002)). Some learning environments where learners can learn by teaching to computer agents as a learner have been developed: SimStudent (M. Sano et. al. (2010)), Betty's Brain (K. Leelawong and G. Biswas (2008)) and so on. In learning by teaching, a learner as a teacher compares a learner agent's incorrect answer with his/her own answer to find mistakes from the learner agent's answer. The learner should find not only the learner agent's mistakes in the answer but also the mistakes in the solution. This requirement enforces the learner to be aware of the related knowledge, some knowledge used in the incorrect solution, and the problem solving strategies to generate a series of hypotheses about the learner agent's mistakes in the solution. We think this process assists the learner in following two types of thinking which rarely occur in general learning.

A. To associate between knowledge used in the learner's problem solving and related knowledge of the problem

When a learner compares his/her own answer and the learner agent's answer, the learner can learn the difference between knowledge used by the learner agent in its wrong answer and knowledge used by his/her correct solution. It leads the learner to be aware of the specific feature of the knowledge used in the correct solution. In this paper, the knowledge used in the incorrect answer is named "related knowledge (RK)" of the knowledge used in the correct solution.

B. To be aware of strategies of the problem solving that is a kind of meta cognitive knowledge

In general, many learners are not aware of their problem solving strategies (PSS). A PSS is a kind of meta-cognitive knowledge. To be aware of the PSS leads learners to activate their meta-cognition (S. Hirashima (2006)). Activation of meta-cognition has important influence on reviewing and streamlining meta-cognitive activities. Increasing the ability of learners' problem solving by education with

activating their meta-cognition was reported in (I. Yoshino and S. Shimanuki (2012)) and (H. Kinoshita et. al. (2007)). We designed our learning environment to lead learners to be aware of their PSS in their diagnosis of the learner agent's PSS used in its incorrect answer.

However, even if a learner can solve a problem his/herself, he/she often cannot guess the cause of the learner agent's incorrect answer. Especially for the learner who was not aware of his/her PSS, it is difficult to diagnose the learner agent's mistakes in its PSS. To support such learners, we introduce an agent which supports learners' teaching activities in a "learning by teaching" learning environment. This teacher agent helps learners stuck in their diagnosing of learner agent's PSSs in its incorrect answer. This supports learners in their "learning by teaching" and leads them to be aware of RK and their PSSs.

2. Design of Learning Environment

2.1 Basic Learning Design in the Environment

In this learning environment, a learner acts as a teaching assistant for teaching phyloanalysis problems for metallic ion. The learner leads the learner agent to solve the problem. When the learner becomes stuck in leading, he/she can request the teacher agent's supports for diagnosing the causes in the learner agent's incorrect answer. The learning process starts after the learners solve the problems correctly. Activating learners' meta-cognition, the causes of learner agent's incorrect answers should be logically diagnosed by using knowledge for chemistry and PSSs. To lead learners to diagnose the causes of learner agent's incorrect answers his/herself, we designed teacher agent's dialogue strategies (DSs) to avoid teaching the cause directly and supporting the learner to diagnose his/herself.

2.2 Dialogues for Supporting Learners as Teaching Assistants

Table **1** shows a dialogue in which the learner agent has the incorrect chemical knowledge. The teacher agent's typical reply, realized by the following (i) to (vi) DSs, are noted. The dialogue has 3 participants: the learner, the learner agent and the teacher agent. The learner is a human learner, and the others are computer agents. We expect the dialogue before the learner identifies the difference between the learner agent's answer and his/her answer lets the learner become aware of his/her and the learner's PSSs, and the relationships between the learner's incorrect answers and his/her correct answers. As for the dialogue once the learner identifies it, the dialogue will let the learner become aware of the knowledge the learner already has and the RK in the learner agent's answer.

(i) Ask the learner what types of PSSs do the learner agent use.
The purpose of this DS is to let the learner become aware of which PSS should be used to solve the problem. This strategy can show variations of the strategies. A strategy the learner is interested in is a trigger for the learner to ask the learner agent and the teacher agent based on the strategy.

(ii) Ask the learner if the learner solved the problem with the PSS the learner agent used; is the answer the same as the learner agent's.
The purpose of this DS is to let the learner become aware of the relationship between the learner agent's incorrect answer and the PSS the learner agent used to solve the problem. This relationship invokes chemical knowledge related to the strategy, and leads the learner to compare the invoked knowledge with his/her knowledge.

(iii) Ask the learner the differences between the learner's answer and the learner agent's answer.
The purpose of this strategy is to let the learner become aware of the difference between his/her correct answer and the learner agent's incorrect answer.

(iv) Ask the learner why the step is different from the learner's correct answer?
The purpose of this DS is to let the learner become aware of the part of the learner agent's mistakes. It is essential to diagnose the causes of the learner agent's incorrect answer because the learner should imagine what types of PSSs and/or chemical knowledge the learner agent has used to write the incorrect part. This activity invokes chemical knowledge which was not used when the learner solved the problem his/herself.

(v) Suggest some causes of the learner agent's incorrect answer which are diagnosed by the teacher agent, and their reasoning.
The purpose of this DS is to let the learner narrow down the causes.

(vi) Ask the learner about RK based on the teacher agent's diagnosis.
The purpose of this DS is to let the learner confirm knowledge needed to diagnose the causes of the learner agent's incorrect answer. The learner cannot understand some RK is supported by the dialogue in order to teach the right knowledge.

Table 1: Dialogue for Supporting Learner as Teaching Assistant (Problem: "Isolate $\mathbf{Ca^{2+}}$ and $\mathbf{Cu^{2+}}$")

S	L	Utterance
Before he/she identifies the difference between the learner agent's answer and his/her answer.		
T	H	Hello. Mr. Sato's answer is incorrect due to the mistakes in his chemical knowledge or problem solving strategy. Shall we diagnose the causes for his incorrect answer?
H	T	I have trouble; I cannot understand the cause for his incorrect answer.
T	H	OK. Let's diagnose them together.
T	H	What do you think are types of problem solving strategies Mr. Sato used for the problem? (DS (i))
H	T	A strategy based on the group of materials.
T	H	If you solve the problem with the problem solving strategy based on the group of materials, is the answer the same as Mr. Sato's? (DS (ii))
H	T	No.
T	H	That's right. The answer solved with the problem solving strategy based on the group of materials is not the same as Mr. Sato's. The answer is as follows (The teacher agent shows correct answer).
T	H	What do you think the differences are when you compare the answer of yours and Mr. Sato's? (DS (iii))
H	T	At the 1st step.
T	H	Yes. The step where the difference was, is related to the cause of his incorrect answer. Thinking of the problem solving strategy used by Mr. Sato, do you diagnose the cause of his incorrect answer again?
After he/she identifies the difference between the learner agent's answer and his/her answer.		
T	H	Why do you think the step is different from our answer? (DS (iv))
H	T	I don't know.
T	H	OK. Shall we discuss why the step is different from our answer?
T	H	There is a possibility that Mr. Sato misunderstands the relationship between precipitated operations and the effect of the operation. It is because he answered incorrectly for only one precipitated operation however all of the others are correct. There is another possibility that Mr. Sato misunderstands the group of the material or operations which isolate the group. Because of this, the operations in his answer do not correspond to the group of the material. (DS (v))
T	H	When you add H_2S into the acid liquid, what group of materials do you expect to precipitate? (DS (vi))

H: the learner (Human), T: the teacher agent, L: the learner agent (named Mr. Sato)

2.3 Problem Solving Engine with Problem Solving Strategies

The learner agent and the teacher agent should explicitly handle the knowledge used in their problem solving process. This knowledge is not only chemical knowledge but also problem solving strategies (PSSs). A PSS is defined by the goal of the problem, conditions of the problem to apply the strategy, chemical knowledge which is essential for the strategy, and its operations. This structure of the PSS enables the learner agent to support the following 3 types of strategy mistakes.

A) The learner agent cannot choose the correct PSS because it does not have enough chemical knowledge to use the strategy.
B) The learner agent cannot insert the operation of its PSS into the correct position within the existing operations.
C) The learner agent cannot use its PSS correctly because its chemical knowledge invoked in the operations of the PSS is incorrect.

3. System Overview

Figure **1** shows the architecture of our learning environment. At first, the learner chooses a problem, and a learner agent begins based on a pattern from the learner agent patterns database. The learner agent and the teacher agent solve the problem by using chemical knowledge and PSSs. The teacher agent compares its answer with the learner agent's answer, and creates its hypothesis for the cause of the learner agent's incorrect answer. The learner diagnoses the cause of the learner agent's incorrect answer by asking the learner agent. The learner shows the teacher agent his/her hypothesis. If the teacher agent accepts the hypothesis, the learner agent is taught and fixes the incorrect answer.

The learning environment contains some databases. The chemical knowledge databases consist of the knowledge of the materials, attributes of materials, hierarchy of materials, group with order, and group categorization. A PSS contains the operations written by control and execute templates as follows.

(Essential chemical knowledge) Knowledge of the group based on the ionization tendency
(Problem conditions) Materials in the group used in the problem
(Operations) Categorize the isolating target materials into 3 groups: not precipitable, precipitatable in acid liquid, and precipitable, when H_2S is added. … (skip the rest)

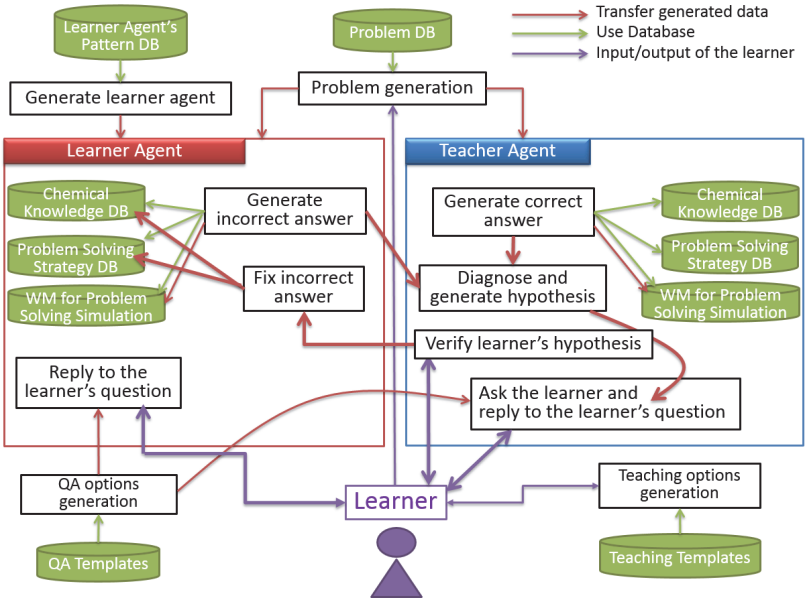

Figure 1. Architecture of our learning environment

4. Preliminary Evaluation

4.1 Evaluation Process

We have the following 3 hypotheses regarding the advantages of our learning environment.

- (Hypothesis 1-1) Our learning environment is more effective for learners who are aware of the relationship between knowledge used in their problem solving and RK than their general activities.
- (Hypothesis 1-2) Our learning environment is more effective for learners who are aware of their PSSs than general activities.
- (Hypothesis 2) Learners' occasions for getting stuck in their "learning by teaching" are reduced by support from the teacher agent.

(1) The subjects, 5 university students, solve 3 problems within a limited time period of 30 minutes per problem. After solving each problem, they write down as much chemical knowledge and PSSs they were aware of in their problem solving process as possible (Sheet a-1).
(2) The subjects use our learning environment, and teach the learner agent within the duration of 30 minutes per problem. The subjects write down "What did you think to do next when the teacher agent asked you and/or helped you?" and "Why did you think so?" (Sheet b).
(3) After the activities, the subjects write down as much chemical knowledge and PSSs they were aware of (2) as possible (Sheet a-2), and the strategies they were aware of in order to diagnose the causes for the learner agent's answer (Sheet c).

We prepared 3 types of problems corresponding to the learner agent's mistakes.

- Condition 1: stuck in choosing PSS. Problem: Isolate Ba^{2+} and Ag^{+} and Ca^{2+}
- Condition 2: stuck in using PSS. Problem: Isolate Cu^{2+} and Fe^{3+} and Ca^{2+}
- Condition 3: stuck due to incorrect chemical knowledge. Problem: Isolate Ca^{2+} and Cu^{2+}

As for condition 1, the learning agent cannot choose the correct PSS as it does not have enough chemical knowledge to use the strategy. As for condition 2, the learning agent cannot insert the operations of its PSS into the correct position in the existing operations. As for condition 3, the learning agent cannot use its PSS correctly as its chemical knowledge invoked in the PSS is incorrect.

4.2 Results and Discussions

From (sheet a-1) and (sheet a-2), the chemical knowledge these subjects were aware of is shown in Table **2**. The PSSs these subjects were aware of are shown in Table **3**. As for hypothesis 1-1, (sheet a-1) in Table 2 shows the subjects were aware of chemical knowledge and/or operations in a PSS. In comparison with (sheet a-1), (sheet-a-2) shows the subjects were aware of them with RK. One subject commented he/she was aware of the chemical knowledge the learner agent used.

The comments from (sheet a-2) in Table **3** show these subjects were aware of more specific PSSs than (sheet a-1). In (sheet a-1), most subjects only focused on the order of the operations. However, in (sheet a-2), these subjects were aware of the strategies to branch the operations based on the group of materials, and to modify the operations based on the liquid acidity. This indicates the subjects were aware of RK. Even if it were possible the subjects were implicitly aware of them before using the environment, (sheet a-2) shows they began to use them explicitly. These follow our hypothesis 1-2.

(sheet b) is shown in Table **4**. In the DS (i), all 4 subjects who requested the teacher agent's support commented of been aware of the PSSs. In the DS (ii) to (v), the comments show the teacher agent's support lets these subjects become able to narrow down the learner agent's mistakes. In the DS (vi), the comments show the teacher agent's support allows these subjects try to fix his/her incorrect knowledge or to investigate more details of the knowledge. On the whole, these dialogues tend to succeed in letting the learners become aware as described in section 2.2.

Table **5** shows how many times each subject requested the teacher agent's assistance. The results show no case where the subject can succeed in his/her diagnosis by assistance from the teacher agent. However, all subjects commented they could narrow down the learner agent's mistakes. With both things considered, this learning environment cannot allow learners to completely succeed in their diagnosis as our hypothesis 2, but it has the effects of letting learners narrow down the agent's mistakes.

(sheet c) is shown in Table **6**. It shows 2 subjects made a diagnosis strategy of the difference between the learner agent's answer and his/her answer. This diagnosis strategy is one of the thinking processes expected for the learner. They achieved the diagnosis strategy as a metacognitive knowledge as well. Such a diagnosis strategy is related to the thinking required by hypothesis 1-1 and 1-2.

Table 2: What types of chemical knowledge are subjects aware of?

Types of chemical knowledge	**Number of subjects**
After problem solving by his/herself (sheet a-1)	
How operations can isolate each material?	4
Ionization tendency	1
Periodic table	1
Color of precipitates	1
Flame reaction	1
Oxidation reduction reaction	1
After using our learning environment (sheet a-2)	
Relationship of the group and the order of isolating material	3
Relationship of how to isolate Ca^{2+} and Fe^{2+}, and liquid acidity of sulfate salt and carbonate	1
Relationship of oxidation reduction reaction and Fe^{3+}	1
To check chemical knowledge used in the learner agent's answer	1

Table 3: What types of problem solving strategies are subjects aware of?

Types of problem solving strategies	**Number of subjects**
After problem solving by his/herself (sheet a-1)	
I thought the order of the operations and the materials could be isolated by.	4
Isolate first the material which can be isolated at the time.	2
When an operation which has a bad effect for following operations is needed, operations for recovery are planned.	2
After using our learning environment (sheet a-2)	
Branch operations based on the group of the materials.	2
The necessity of the operation in the operations.	1
Avoid the operation which creates strong acid because it is difficult to revert.	1
I focused on the operations: oxidation, reduction and boiling to remove H_2S.	1

Table 4: Comments about the dialogue with the teacher agent

DS	Comment
(i)	I confirmed which problem solving strategy I used. I tried to ask the details of the problem solving strategy I chose. (3 subjects)
(ii)	I confirmed my focusing point was the same as the teacher's (teacher agent's).
(iii)	I could diagnose where the learner (learner agent) made mistakes. I could understand where I should check the learner's (learner agent's) solution, however, I cannot understand how to do so.
(iv)	I could not understand the difference.
(v)	I decided rough design of what should I do. (2 subjects) I tried to confirm whether I understood the problem solving strategy I chose.
(vi)	I confirmed my knowledge was correct. I confirmed my knowledge was not correct. This dialogue let me know more detail about the knowledge asked by the teacher.

Table 5: How many times subjects request the teacher agent's assistance? (A: Achieved, G: Gave up)

	Subject A	Subject B	Subject C	Subject D	Subject E
Condition 1	7 times (G)	0 times (A)	0 times (A)	0 times (A)	0 times (A)
Condition 2	6 times (G)	0 times (A)	0 times (A)	0 times (A)	6 times (G)
Condition 3	7 times (G)	4 times (G)	0 times (A)	7 times (G)	7 times (G)

Table 6: What types of problem solving strategies are subjects aware of for diagnosing the causes of the learner agent's incorrect answer?

Types of problem solving strategies	Number of subjects
Imagine what the learner agent is thinking.	3
Analyze differences of my answer and the learner agent's answer.	2
Analyze differences of the teacher agent's hypothesis and the learner agent's answer.	1

5. Conclusion

In this paper, we proposed our learning environment where a learner can learn by teaching in his/her teaching assistant activities with a teacher agent. Our preliminary evaluation gives an insight that our learning environment let learners become aware of the relationship between his/her chemical knowledge, the related knowledge and their problem solving strategies. However, it could not let learners diagnose successfully. Our future work is to re-design the teacher agent's assistance for the learners who cannot diagnose successfully even though they can narrow them down.

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