Engaging Reflective Thinking in Learning Mathematics Word Problems by Using a Personal Tutoring Agent

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Abstract

This paper presents a concept of an e-learning system which supports reflective thinking. A Chatbot personal tutoring agent (PTA-Bot) is proposed. Chatbot technology and ontology technology are combined to boost an effective adaptive e-learning system to help students to overcome difficulties in mathematics word problem symbolization and to motivate them to reflect their own thinking during solving problems.

Keywords: Critical Thinking, Reflective Thinking, Chatbot, Adaptive E-Learning System, Word Problem

1 General Instructions

Reflective thinking (RT) is sometime used as synonym of critical thinking (CT), on the other hand, it is a part of the CT process referring specifically to the processes of analyzing and making judgments about what has happened [1, 2]. RT involves personal consideration of one’s own learning. It considers personal achievements and failures and asks what worked, what did not, and what needed improvement [3, 4]. It reminds students to think and concern about their own thinking.

Today’s world is becoming more complicated. Merely having knowledge or information is not enough. To be effective in the workplace (and in their personal lives), students must be able to solve problems to make effective decisions; they must be able to think critically [5]. To say that, they would have to concern or rethink more about their own thinking before making any decision. As Danielsen mentioned in [6], RT helps students develop higher-order thinking skills by prompting students to relate new knowledge to prior understanding, think in both abstract and conceptual terms, apply specific strategies in novel tasks, and understand their own thinking and learning strategies.

In this research, a case study we mainly focus on is to learn how to symbolise mathematical word problems which is the most difficult implicit step (both for learning and teaching) in solving word problems. These are some reasons of its difficulties in a class room: (i) there is no fixed steps to follows, (ii) its solution is not unique, (iii) students have various capabilities, teacher cannot take care each student personally, (iv) students hesitate to ask a teacher in the class, and the one reason that I absolutely agree with is from [7], (v) students are presented with inconsistent models of problem solving that contradict the logical processes they have learned in other courses and in everyday life.

Students cannot effectively learn how to symbolise word problems by remembering solving strategy step by step, but they have to learn to think critically for reflecting self-thinking to better make a rational decision, even in their dairy life. To engage students to reflect their thinking during practicing on e-learning system, in this research we propose a Chatbot Personal Tutoring Agent (PTA-Bot). PTA-Bot is developed based on Chatbot system by enhancing its semantic power in asking higher-order question and analyzing students’ responds for feeding appropriated exercise which is personally suitable for individual student.

In the next section, we present some related works and technologies which are necessary for developing our research. In the Section 3, the architecture design of the system and learning
environment is shown and then activities and exercises which are used in the system are described in Section 4. An example of expected result is presented in Section 5 and in Section 6, the evaluation method is provided. Finally, discussions and future work are expressed in Section 7.

2 Related Works

Ontology is a branch of philosophy which has been widely used in recent years in the field of artificial intelligence and computer and information science, especially in domains such as intelligent information integration, knowledge representation, information retrieval and extraction, workflow and database management systems [8]. There are a number of definitions for describing what is ontology. One of the most widely use is: Ontology is a formal, explicit specification of a conceptualisation [9]. The role of ontology in the field of web-based learning is often underestimated [10]. It has usually been used to describe learners and their profile also to design the learning content and the relation between learning concepts.

In the past ten years, an increasing amount of research has been seen on designing personalised learning systems to deliver learning contents according to the need of particular learner [11]. A personalised e-learning system, namely a personalised intelligent mobile learning system (PIMS), was proposed by Chen et al to promote individual learner’s ability of reading English news [12, 13]. It is based on the item response theory that considers vocabulary ability of the learner and learning memory cycle to provide personalised learning [14]. Baylari et al. [15] proposed a personalised multi-agent e-learning system that presents adaptive tests, and acts as a human instructor, and gives the learners a friendly and personalised teaching environment.

Recently, ontology technologies have become a trend to promote adaptive learning services due to recent advancement of semantic web technologies and tools that allow developers to create meaningful personal user profiles that can assist the learners during the learning process. Vassileva et al. [16] designed learning ontology graphs organizing multimedia learning objects (LOs), and metadata for both the ontology and LOs. Their platforms which consist of an authoring tool, an instructor tool and an adaptation engine controlling the content delivery that adaptable to individual learners. In some works, an ontology was used to model user profiles in different applications like semantic web searching, information retrieval, or natural language processing. Gemmis et al. [17] proposed an extension of the vector space retrieval model in which user profiles are learned by a content-based recommender system. Pan et al. [18] designed a learner ontology and a learning resource ontology for semantic analysis and algorithm for ontology semantic to develop a semantic-based search method for personalised e-learning.

Chatbots are computer programs interacting with users via natural languages. Our choice of choosing a Chatbot is to build a friendly dialog interface, as Zadrozny et al. mentioned in [19] that the best way to facilitate human computer interaction (HCI) is by allowing users “to express their interest, wishes, or queries directly and naturally, by speaking, typing, and pointing”. The original Chatbot, ELIZA, was created in the 60’s by Joseph Weizenbaum, [20], to emulate a psychotherapist in a clinical treatment. However, Chatbots are not only built to mimic human conversation, and entertain users. It can be useful in several applications, such as, education, information retrieval, business, and e-commerce [21]. In last years Chatbot have played a prominent role as human computer interfaces [22]. Knill et al. [23] developed the Sofia Chatbot to assist in teaching Mathematics. The Sofia Chatbot has the ability to chat with users, and at the same time, to chat with other mathematical agents such as Pari and Mathmatica to help in solving Algebra problems. Sofia mainly focuses on mathematics and other common knowledge to make it friendly to use. [23] Teachers could use a Chatbot to look for problems (where students have problems, what questions students ask, and the generated logs file could be accessed to gauge student learning, and students weaknesses) while students use it to solve problems. [21]

This paper presents a concept idea of designing an alternative adaptive e-learning system, called PTA-Bot, to promote reflective thinking. As mentioned previously, we decided to operate the system via a Chatbot because we would like to simulate friendly learning atmosphere to attract
students’ attention. It will be used as a medium to facilitate appropriate learning materials from analyzing conversation dialogs and students’ actions or responses.

3 PTA-Bot

3.1 Learning Environment

In this learning environment, a student chats with the PTA-Bot on the ChatSpace, and does any activities on WorkSpace in which chatting conversation is related to activities on the WorkSpace, refer to Figure 1(b). In Figure 1(a), while the student chatting with the agent on ChatSpace, the agent can (i) ask the student to do an exercise (the exercise will appear on the WorkSpace), (ii) show some examples to answer to the student question (detailed explanation and some examples will appear on the WorkSpace), (iii) order the student to work on a task provided on the WorkSpace, and (iv) give feedback to the student for his action both in the ChatSpace and WorkSpace.

3.2 Architectural Design

In this research, we propose the Chatbot personal tutoring system which support critical thinking. As shown in Figure 2, the proposed architecture has four layers, comprising of learner layer, agent layer, semantic layer, and database layer.

Figure 2. Architecture Design of PTA-Bot.

**Learner layer** is the layer that interacts with a student, i.e., it is the layer of user interface...
which is divided into two main spaces, the Workspace and the ChatSpace, see Figure 1(b). **Agent layer** contains three agents: a facilitator agent, a response agent, and a conversation agent.

- **Conversation agent**: This agent drives the Chatbot. It acts as a human tutor that communicates with a student. It is trained (supervised learning) to ask questions to inquire the student ability, to activate student’s learning, and to encourage the process of reflective thinking. It answers to the student’s questions and give explanation as needed, similarly as existing Chatbots using the knowledge represented in the underlying ontologies and analyzed information from the response agent, shown in Figure 2. It asks the student to work on Workspace and gives feedback related to the student action on the Workspace. Otherwise, It keeps and stores conversation log and feed to the response agent.

- **Response agent**: This agent records conversation, learning action (such as mouse action), learning duration for each task, learning responses in conversation log, etc. And stores them in the learner database. Moreover, this agent also analyzes the results from student responses, and diagnoses student’s learning problems, like a human tutor, and then send information to the facilitator agent and conversation agent to recommend the appropriate learning materials or response messages and interactions to the student.

- **Facilitator agent**: This agent is based on the requests of the response agent which analyzes conversation feed, from the conversation agent, and metadata of LOs and subject content, from LOs and content ontologies, to select the suitable exercises or activities from LOs database.

**Semantic layer** consists of four ontologies which are provided by domain experts. These ontologies keep semantic structure and relations of concepts in each data knowledge domain;

- Learner ontology: learner’s characteristics such as ability and learning styles.
- Pedagogy ontology: pedagogical approaches and instructional designs.
- Content ontology: concepts of subject content, related information, and problem structures.
- LOs ontology: metadata about each LO are preserved.

**Database layer** contains three databases, a learner profile database which stores user profile, an LOs (learning object) database which store learning materials as learning objects, and a content database which stores the subject content and related information. Data in the learner database is collected from the response agent and being kept under student’s login user and the other two databases are provided by teachers.

4 Flow of Learning Activities

In this section, a flow of learning activities is presented. The original problem solving step was proposed by George Polya. It composes of (i) understand a problem, (ii) devise plan, (iii) carrying out the plan, and (iv) examine the solution. The most important step to successfully solve a word problem is to understand the problem, as Polya stated in his book, [25]:

“It is foolish that you answer a question you do not understand. It is sad to work for an end that you not desire”.

To understand a problem, a student has to be able to answer these following questions.

- Do you understand all the words used in the stating problem?
- What are you asked to find or show?
- Can you restate the problem in your own words?
- Can you think of a picture or a diagram that might help you understand the problem?
- Is there enough information to enable you to find the solution?
- Do you need to ask a question to get an answer?

You can see obviously, the listed questions can help students to understand a problem by engaging them to remind their thinking process. It
goes with our aim to encourage their own thinking during solving problem. We decide on next learning activities mainly based on the previous questions and referred to problem solving methods mentioned in [25-28].

**Problem posing and changing:** Problem posing and changing exercises aim to engage students to rethink and be aware of semantic structure of the problems. A student who can symbolise the problem will be asked to restate the problem from the result equation and be asked to changing some constrains in the problem go meet the expected solution.

**Problem extraction:** This activity mainly provokes students to be aware of these questions, What is the unknown? What are the data? And What is the condition? In this section a student will be asked to underline important information in the problem.

**Easier example exercise:** Certain students have no idea about solving word problem they do not know how to start they do not understand the problem’s context. In this situation, it is necessary to explain, to give term definition, and to facilitate them some easier or simple examples to build up their basis and to gain more understanding.

**Problem completion and classification:** In these exercises, a student might be asked to complete incomplete problems and/or give some reasons to classify given problems. These exercises aim to promote students to be aware of problem structures and make them realize about correctness and completeness of a problem, not to just believe that all given problem is correct.

After the student logged-in and accessed to the system, other than chatting with PTA-Bot, the system provides exercises and activities for students. Since, we are concerned about varieties of student’s backgrounds and their performances, the system would be able to facilitate adaptively suitable exercises, activities, or contents for each student. From Figure 3, at first, students will be asked to symbolise the problem straightforwardly if they know how to symbolise the problem, they will not get bored at a very basic activities or explanation but they would be offered with more challenging activities to reflect their thinking. Here we use problem posing and problem changing exercise as a reflective thinking tool. If the student could not symbolise the problem correctly, he will be asked to illustrate parts of problems in problem extraction exercises to ensure whether he does really understand the point and structure of the problem. If he can do it really well he will be asked again to symbolise the problem, otherwise, if he is not clear to illustrate parts of the problem, exercises for enhancing his vocabulary and awareness of problem semantic structure, such as exercises on problem completion or problem classification, will be served to the student. Then he would be asked again to distinguish the problem’s components before asking to input the solution again to go further to work on problem changing exercises.

5 Expected Results

When a student logins and accesses the system,
the conversation will be started by the PTA-Bot to make the student feel comfortable to work in the system, as shown in Figure 1(b). As stated in Subsection 3.2, the PTA-Bot communicates with a student on the ChatSpace and delivers conversation-related materials in real-time on the Workspace. From Figure 1(b), in the last chat box from PTA-Bot, it asked the student to select one problem to process, then in the WorkSpace, selection problems will appear. Moreover, when the student performs some action on the WorkSpace, the PTA-Bot is expected to have ability to realize any actions on the WorkSpace by communication among the three agents.

Figure 4 shows the scenario after the student chose a problem. This following dialogue details more about the situation in Figure 4 and what would happen further.

(Continues from Figure 1(b), after the student chose a problem.)
PTA-Bot: Thank for choosing!
PTA-Bot: Please, read the problem carefully! If you can symbolise it, put your solution in the box beneath the problem. (Blank boxes and the input tool appear in the WorkSpace, see Figure 4(a).)
Student: //input solution
PTA-Bot: Excellent! It’s correct!
PTA-Bot: From your solution, which appearing problems can be symbolised equivalently as that solution? (Show list of questions in the WorkSpace, see Figure 4(b).)

*(If the student chose the correct choice.)
Student: //Click on the correct choice.
PTA-Bot: Great! It’s correct!
PTA-Bot: Please use the information appearing in the WorkSpace to form the problem that contain the same equation. (Information appears in the WorkSpace.)

**(If the student chose the correct choice.)
Student: //Click on an incorrect choice.
PTA-Bot: Could you please symbolise the problem you just chose? (Blank boxes and the input tool appear in the WorkSpace.)

From the previous example dialogue, the student is asked to select a question which can be symbolised equivalently as the initial problem to encourage them to rethink about the solution he submitted. Moreover, the student will be engaged to rethink about how to get the solution by Problem posing/changing activities. Such as in (*), in the dialogue, the student was asked to form a new problem which contains the same equation of the main problem. Or in (**), if the student selected a problem which cannot be represented by the same equation, the agent will not be announce his incorrectness but it will ask him to rethink about the solution of the problem he chose.

![Figure 4. System simulation.](a)

![Figure 4. System simulation.](b)

6 Evaluation

The main objective of the system is to promote RT via e-learning system. The consequence of reflective though may motivate students to think more critically that would support them to deeply understand the content they are learning. One way of our choices to evaluate our system performance is to evaluate the
change of students’ proficiency, who practice on the system, in solving math word problem using pre-test and post-test comparing with a control group of students, who do not use the system. In pre- and post-testing, other than score comparison, student working-out details will be analysed to observe some critical thinking depositions, such as reasoning, using and mentioning credible source, and relevant thinking to the main point alternative thinking. Students’ interaction and conversation logs which are recorded by the system can be also used to analyse some aspects of ongoing interacting situation. This information can be used to observe how students interact with the agent, e.g. do they interact more critically? and does the system help or motivate them reflectively think?

7 Conclusion

In this paper we propose an idea to promote CT in self-learning system. The specific part of CT which is promoted in this work is reflective thinking. A case study that we use in this research is to teach student in solving mathematics context problems using algebraic method in which we mainly focus on the first step of problem solving that is to symbolise a problem, which is the most important and the most difficult step in solving any context problems. To be able to symbolise a problem, it is very important to understand the problem clearly. To understand a problem the questions in Section 4 have been concerned. As you see, those questions do not only help a student to understand a question, but also engage him to rethink of his understanding. Exercises and activities which are used to support this idea are (i) problem posing and changing, (ii) problem extraction, (iii) giving easier example, (iv) problem completion and classification, and (v) asking higher order questions. To implement our idea, we propose a personal tutoring agent, namely PTA-Bot. User interface of the PTA-Bot has two sections, the WorkSpace and the ChatSpace. The ChatSpace is developed by Chatbot technology. This is used to create friendly learning atmosphere. The WorkSpace is provided to serve learning materials which are related to the conversation. This mimics the nature of teaching by human that teacher communicate with students and ask the students to do some things. Ontology technology is required to boosted the semantic and consistency performance of the system.

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