ABSTRACT

Learning-by-teaching is an open-ended and self-directed activity, which shares a number of characteristics with exploratory and constructivist learning. A natural goal for effective teaching is to gain a good understanding of domain knowledge before teaching it to others. Teaching also includes a process for structuring knowledge in a communicable form, and reflecting on interactions with students during and after the teaching task. Current computer-based learning-by-teaching environment (LTE) can provide middle school students with opportunities of assuming the role of teacher in an interactive environment that fosters active learning. However, they are not directly supported to reflect on their goals, content
knowledge, and thoughts as they teach the agent in the LTE. They need further support to
guide their reflective teaching practice for better learning. This paper proposes the
incorporation of diagrammatic representations and reflection prompts into the LTE to
courage students to pursue their teaching activities with the opportunity to reflect and self-
explain their experiences. A pilot study on the benefits of introducing diagrammatic
representation and reflection prompts and the further development of the LTE with reflection
support is described.

INTRODUCTION

Studies have shown that the paradigm of learning-by-teaching can provide cognitive and
motivational benefits for the tutor. Cohen (1986) found that preparing to teach “facilitates
long-term retention, as well as aiding in the formation of a more comprehensive and
integrated understanding”. Gaustard (1993) observed that “student tutors often benefit as
much or more than their tutees”. Biswas, Schwarz et al. (2001) reported that “the challenge of
teaching others appears to create the sense of responsibility that is highly motivating to
individual of all ages”.

To design a computer-based learning-by-teaching system, one focus is to support the student
tutor to assume different phases of teaching activities with characteristics of constructivist
learning and social interaction. A natural goal for effective teaching is to gain a good
understanding of domain knowledge before teaching it to others (Biswas et al, 2004).
Teaching also includes a process for structuring knowledge in communicable form, and
reflecting on interactions with students during and after the teaching task (Chi et al, 2001).
One typical example of learning-by-teaching system is Betty’s Brain, a teachable agent
environment in which a secondary school student can construct a concept map to build his
own knowledge structures effectively, trace responses of the agent transparently, and view his own progress in this process.

In this paper, we introduce the combination of diagrammatic representations and reflection prompts to enhance Betty’s Brain, and apply it to the domain of elementary economics for secondary school students. Diagrammatic representations can facilitate students’ understanding with more visually explicit information and constrain inferences which can guide their cognitive processing. However, diagrams are sometimes too abstract and technical for students to utilize in the learning-by-teaching environment. So, the reflection prompts are designed to complement the diagrams to support students to reflect on their goals, content knowledge, and thoughts as they pursue the teaching activities. We hypothesize that the student can benefit from this design of learning-by-teaching and be prompted into reflective teaching practice for better learning.

The paper is organized as follows. First, we present an overview of the research literature, including the learning-by-teaching system, diagrammatic representations and reflection prompts. This provides the architectural foundation for incorporating diagrammatic representations and reflection prompts into learning-by-teaching system. Second, the issues of integrating diagrams and reflection prompts with learning-by-teaching are discussed. Third, a pilot study on how well the incorporation of diagrammatic representations and reflection prompts deliver its proposed benefits to middle school students in learning-by-teaching environment is provided. Lastly, future directions for this work are described.
BACKGROUND

Learning-by-Teaching System

The idea of implementing learning by teaching system is based on the widespread educational practice of peer tutoring; where a more-able student (the *tutor*) is paired with a less-able partner (the *tutee*). The *tutor* takes on the role of a teacher and provides knowledge and support when the *tutee* encounters difficulties.

Biswas, Schwarz, Leelawong and et al (2001, 2003) have built a learning-by-teaching system called Betty’s Brain where students explicitly teach by constructing concept maps and directly receive feedback about their teaching.

![Figure 1. A Learning-by-Teaching Environment: Betty’s Brain](image)

Students’ teaching practices in Betty Brain can be divided into four phases: (i) the Prepare to teach phase, where students learn the domain knowledge independently (ii) the Teach phase, where students impart knowledge to the agent Betty by means of a dynamic concept map interface, and access content materials as needed to learn information for teaching,(iii) the Query phase, where students ask Betty questions (using question templates) which she
answers by reasoning with information that the student has taught her, and (iv) the Quiz phase, where students evaluate how well they have taught Betty by observing her performance on a quiz.

**Diagrammatic Representations**

A picture is worth of thousand of words. The diagram or diagrammatic representation is a type of instructional visual that is widely used interdisciplinarily. Lowe (1993) summarized the advantages and disadvantages in using diagram in instruction. Diagram can simplify the subject matter by reducing it from a three-dimensional to a two-dimensional depiction which becomes easier to observe. It also provides a variety of revealing views of the subject matter that expose important parts of the structure, while removing unnecessary detail that is present in the real world but has no significance in terms of the overall structure.

However, there are potential disadvantages in using diagrams, particularly with students who are not skilled in utilizing available resources. Students are initially accustomed to more realistic picture of real world and unused to deal with the abstract, technical representations. And they are required to mentally put together the difference views conveyed in the diagram, which is a taxing task for those who lack specific skills of mental manipulation. Additionally, students need to integrate these components with the textual information in the captions and labels, which involves coordination of scattered items of information that must be drawn together to form a coherent whole.

So, the deficiencies in students’ knowledge and skills should be considered when developing e-learning environment involving diagrams. Learners may need to be given considerable support to help them deal with diagrams presented during the learning process. This paper
tries to introduce reflection prompts as one possible approach to aid students to learn to understand and make use of diagrams in the computer-based learning-by-teaching systems.

**Reflection Prompts**

Many research programs have focused on encouraging reflection. The approaches in these programs vary in their definitions and ways of promoting reflection, e.g., questions from teachers, peers, software, or texts can promote learning by eliciting explanations. Students provide explanations to other students’ questions or who explain examples they find in their textbooks seem to strengthen connections among their ideas. Chi and et al. (Chi, Bassok, Lewis, Reimann, & Glaser, 1989) argued that elicit self-explanations lead to improved understanding of texts. Bielaczyc, Pirolli, & Brown (1995) found that students can be trained to give self-explanations when learning LISP, and that this training promotes improved understanding.

White and Frederiksen (1995) showed that success using prompts for reflective assessment in their mechanics curriculum for junior high school students. Students who routinely answered such prompts developed greater understanding of the subject matter and of the inquiry process. Tien, Rickey, and Stacy (1999) explicitly encouraged students to articulate a model of their current understanding of a chemical process and to reflect upon the implications of their observations on their conceptual model. Students who engaged in these and other innovative activities appeared to develop a greater conceptual understanding than did those students in a traditional college chemistry course. Lan (1996) found that students who were scaffolded in self-monitoring did better on exams and had better representations of their knowledge.
Davis (1998) explored two types of reflection prompts: generic prompts and directed prompts. The prompts differ in their specificity and degree to which they are contextualized in students’ activities and afford different focuses for reflection. The generic prompts encourage students to "stop and think," without providing instruction in what to think about. Students can then choose to focus on their own subject matter understanding, on their understanding of the project goals, or on their own learning and thinking. An example of a generic prompt is, "Right now, we're thinking....". The directed prompts, on the other hand, give students hints about what to think about; for example, "what to include in the report" or "pieces of evidence we do not understand." Specifically, directed prompts are intended to elicit planning (in the form of "Thinking Ahead" directed prompts) and monitoring ("Checking Our Understanding" directed prompts).

METHODS

Teaching Activities in Learning-by-Teaching System

The teaching activities of the student tutor in the learning-by-teaching system can be divided into three stages.

1. Gaining understanding of the topic and topic content
2. Structuring knowledge in shared representations
3. Reflecting on the teaching process

The incorporation of diagrammatic representation and reflection prompts is meant to contribute to the teaching interaction between the student tutor and computer tutee in these three stages.
Integrating Diagrams with Learning-by-Teaching Activities

Diagram Aiding Gaining Understanding

A diagram can be used to prepare the student tutor for the topic and topic content that will presented in a unit of teaching by providing a summary of the main points that occur in the unit. It can also provide an analogy that helps the student tutor to relate his existing background knowledge into the new domain knowledge he will encounter. Additionally, it simplifies the content and directs attention by reducing the number of piece information the student tutor is asked to deal with at one time so that the student tutor is not overwhelmed by the complexity.

The supply and demand coordinate diagram in Figure 2, for example, is incorporated in our learning-by-teaching system to exhibit to the student tutor three important relationships in economics: how price affects the supply for the product, how price affects the demand, and the market price of the product.

![Figure 2. Supply and Demand Coordinate Diagram](image)

With the isolating key aspects of topic content shown in this diagram, student tutor can be guided to emphasize the particular features in preparing to teaching even he has not
encountered the subject matter before or normal exposure to the subject matter does not reveal certain features to him.

**Diagram Aiding Structuring Knowledge**

Diagram, in the form of concept map, can play an essential role as the shared knowledge representation between the student tutor and computer tutee. The student tutor generalize from a variety of individual items of information and link them together in meaningful way, then build coherent mental models of these matters into concept maps by making internal and external concepts and relations involved. For example, the abstract concepts and relationships shown in the Figure 2 can be illustrated and enriched in the following concept map to be accomplished by the student tutor.

![Figure 3. Supply and Demand Relationship Concept Map](image)

This concept map provides alternative representations of domain material and additional opportunities to make inferences or predictions, which can help student tutor to better remember and understand the presented topic content. More important, the concept map constructed by the student tutor not only make possible the teaching interaction between student tutor and computer tutee, but also consolidate learning by means of problem solving.
in dealing domain materials and facilitate transfer of the current teaching practice into other contexts.

**Diagram Aiding Reflecting**

Diagrams can also help student tutor “looks back” on the subject matter to refresh their minds and judge how effective their teaching has been by providing a summary that captures the major information dealt with the teaching activities or proposing questions to allow student tutor to determine the overall effectiveness of the teaching.

The original version of Betty’s Brain has provided an animated diagram mechanism as one way to let the student tutor reflect on his teaching when he ask question to the computer tutee.

As shown in Figure 4, when the student tutor asks the computer tutee the question “what happens to the price of oil when social instability increases?”, the computer tutee will make the diagram animated by dynamically showing the reasoning path between the two concepts. It is supposed that this animation can help student tutor reflect on the teaching interaction and help him gain a better understanding of how to model interdependencies among concepts.
Integrating Reflection Prompts with Learning-by-Teaching Activities

The goal of incorporating reflection prompts into the learning-by-teaching system is to provoke different levels of reflection of adapted to the different phases of learning-by-teaching activities. The student tutor is expected to be guided to explore the underlying meaning and situational cues relevant to the domain materials and diagrams, conduct interpedently his teaching activities in the interactive environment to foster active learning.

Prompts Triggering General Reflections before Teaching

The following sets of questions can help the student articulate his philosophy of teaching.

- What is teaching and who is it for?
- Who am I teaching?
- What should we be teaching?
- Why teach?
- Who teaches?

Prompts Triggering Task-Specific Reflections during Teaching

The following sets of questions can help student think about the context and practice of his teaching.

- How do I want students to interact with me?
- What resources should be found to help me teach my student?
- How can I use the tools to help my student understand what I taught?
- Does my student really understand my meaning?
**Prompts Triggering Domain Knowledge Reflections during Teaching**

The following sets of questions can help student think about the domain knowledge he is trying to teach.

- Can I give more elaboration on the concept (e.g. demand of house) I just taught to my students?
- Can I give some reasons on teaching the relationship between the Concept A and Concept B (e.g. if demand of house increase, price of house will also increase)?

**Prompts Triggering Self-Assessment Reflections after Teaching**

The following sets of questions can help student think about his work after teaching. The questions posed in this section are designed to provide students with some space in which he can consider on some aspects of teacher professional development.

- What was the most important thing I tried to teach my students?
- What is/are the most important thing(s) my students will learn from me?
- What did I learn from my students?
- What was I thinking?

**PILOT STUDY**

To assess potential effectiveness and implications to incorporate diagrammatic representations and reflection prompts into learning-by-teaching system, we conducted a pilot study on 10 female students from a local secondary girls’ school. The learning-by-teaching environment we adopted was a revised basic version of Betty’s Brain aimed to teach middle school students about the concepts of interdependence and balance in river ecosystem.
(Biswas et al. 2001). We built a new domain: basic concepts of supply and demand in economics.

The students were divided into two groups, the teach group and the reflection group. The teach group members taught Betty by creating the knowledge structures, generating questions, and analyzing Betty’s responses to questions. The reflection group students, on the other hand, were asked to write down reflection notes to their ongoing teaching practices triggering by the four categories of reflection prompts from pre-prepared sheets and human tutors in the classroom.

The results of analyzing the two groups’ concept maps showed that the students in the reflection group tended to create richer and more complete concept map with more valid concepts and links than their peers in the teach group. In the interview after the evaluation, one student also commented that the learning-by-teaching software “provides teachers with a clear concept map, good for teaching arrangement”, but “too complicated for new learners, they need more verbal explanations and information”.

DISCUSSIONS

Our study with incorporating diagrammatic representations and reflection prompts into learning-by-teaching system demonstrates their potential in promoting involvement in learning among students. Students require additional support, like diagrams and reflection prompt, to efficiently understand the general metacognitive skills, task-specific skills and domain knowledge system for implementing learning. Feedback from the secondary school class and their teachers indicates the potential in the idea of learning by teaching in motivating students and getting them to spend more time in learning on complex and
unfamiliar domains. More extensive studies will be conducted with a focus on implementing diagrammatic representations and reflection prompts into the system and to evaluate their effects on students’ learning in the environment.

REFERENCES


