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Facilitating Metacognitive Skill using Computer-Supported Multi-Reflective Learning: Case Study of MWP Solving

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Abstract: The aim of this paper is to show a framework to facilitate students' metacognitive skill, named CIRCLE, an acronym for "Collaborative discussion, Interactive environment and Representation of thinking process for Computer-supported Learning Environment". It is composed of three reflective learning supporters: an interactive Q/A environment, observable representations of thinking processes and a collaborative platform. In this paper, besides the explanation of the conceptual design of the CIRCLE framework, its implementation on a specific domain, the Mathematical Word Problem (MWP) solving domain, is also illustrated. The MathReflect system is a case study of the CIRCLE implementation. It is designed as a system to train metacognitive skills in solving MWP. In MathReflect, students are encouraged to reflect on their problem solving process by interactive metacognitive questioning environment, and then their problem solving processes are captured as Q/A sequences and Inferential Diagrams. Finally, Q/A sequences and Inferential Diagrams are used as discussion materials in peer's inspection session which corresponds to the collaborative platform in the CIRCLE framework.

Keywords: Metacognition, problem solving, peer assessment, collaborative learning, reflective learning

1. Introduction

The goal of training metacognitive skill is to help leaners to be comfortable with applying meta-level thinking on their cognitive process and become self-regulated learners who can automatically monitor and regulate their learning processes and be aware of their self-difficulties to achieve their tasks. As revealed by Zimmerman (2002), self-regulated learners focus on how they activate, alter, and sustain specific learning practices in social as well as self-contexts. However, learning or training metacognition is not a simple task due to its implicitness. Even so, according to many studies, metacognitive skills can be taught to students to improve their learning (Nietfeld & Shraw, 2002; Thiede, Anderson, & Therriault, 2003). To reduce the difficulties of training metacognition, cognitive targets from self-thinking processes in working memory are shifted to observable thinking processes (Kayashima, Inaba & Mizoguchi, 2005). An observation found in (Cobb, Boufi, McClain, and Whitenack, 1997) shows that there have been strong positive relationships between reflective discourse and development of concept. Similarly to (Akanda, 2013), reflecting on self-cognition enables learners to link their professional development to practical outcomes and broaden the definition of what counts as useful activity. In addition, nowadays, computer-supported environments have been extensively used to support learning. A new and promising research subject thus may be assessing the effects of computer environments, which combine cognitive content with metacognitive support. Such programs can be designed in several ways, for example by using intelligent tutoring systems, educational multimedia systems, virtual agents, metacognitive hints, and so on (Jacobse & Harskamp, 2009). We will therefore adopt a computer-supported learning environment to support reflective learning, which we call computer-supported multi-reflective learning environment.

However, in training metacognitive skills, learners will certainly be overloaded if they are required to think and do several task at the same time, such as thinking of their own ideas, guess others' instances, and learn how to think/behave in discussion at the same time (Seta, Cui, Ikeda & Matsuda, 2012). To deal with the cognitive load problem, learning supports are needed. However, with too many learning supports, learners may get used to those supports and become over-reliant on supports. Some learners may wait for supports and fail to become active learners. This is an issue of concern in our study and we propose a way to address it in section 4.3.

The rest of the paper reveals the detail of the proposed framework and its conceptual design. Then, its implication on mathematical word problem (MWP) solving is illustrated.

2. CIRCLE Framework

Based on the reasons stated in the previous section, in this study, we aim to find a framework to facilitate students' metacognitive skills in a *computer-supported multi-reflective learning environment*. In this study, we aim to find a framework to facilitate students' metacognitive skills in a computer-supported multi-reflective learning environment with scaffolding. The scaffolding will enable the learner to become familiar with using meta-level thinking and reduce their reliance on learning supports. We would specifically like to investigate how to effectively facilitate students to reflect on and be aware of their self-cognition using already existing technologies, i.e., an interactive environment, a graphical interface and a collaborative platform. We name the proposed framework as CIRCLE, an acronym for "Collaborative discussion, Interactive environment and Representation of thinking process for Computer-supported Learning Environment". It is designed to support learners to harmoniously reflect on their self-cognition and scaffold their metacognitive skills via three main components: (i) an interactive Q/A environment, (ii) observable representations and (iii) a collaborative platform. The figure-1 shows the overview of the CIRCLE framework. Firstly, a learner is encouraged to reflect on their thinking process using an interactive Q/A system. Then, they are facilitated to reflect on/externalize her/his thinking process in an observable format in a graphical platform. This observable format of their own thinking processes is used as discussion material in the final step to reflect on their self-thinking process by collaborative activities. Knowledge base (KB) provides learning supports, such as vocabularies and content information to facilitate a smooth learning process and reduce cognitive load. The rest of this section reveals the theoretical background of the proposed framework and shows its implementation on a specific domain, MWP solving, which is used as a case study.

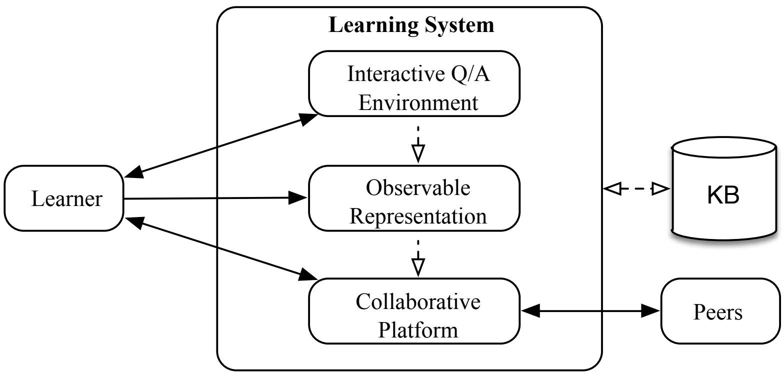

Figure 1. The overview of CIRCLE framework.

2.1 Theoretical background of the proposed framework

Learners' competencies are various. Each leaner has a different performance. One-to-one tutoring with an experienced teacher is known as the best tutoring strategy, because the teacher can observe and respond to her/his students from their reactions or responses. Unfortunately, in the real world situation, there are no enough experienced teachers for all students. To design any learning framework, it is important to consider learners' differences. To deal with this issue, an adaptively interactive environment is considered. One effective method to engage leaners to reflect on their thinking processes is to ask metacognitive questions, such as, "How did you determine this to be true?", "Why does the answer make sense?", etc. There have been many studies show learners who were trained to use metacognitive questions and answers which focused on the formation of relationships/links between prior and new knowledge were better able to understand the contents than students who were trained to ask different kinds of questions, who in turn outperformed the students who were in the control group that not were involved in any training (Schoenfeld, 1985; King, 1994; Mevarech & Kramarski, 2003). An interactive Q/A environment is appropriate in this situation. The system should have various leaners' learning models to effectively deliver appropriate responses to each specific learner. From this point, the questions, '*how to select questions*?' and '*how to deliver questions*?' arise.

Externalizing the thinking process into an observable format helps learners to reduce their cognitive load and enables them to observe and reflect on their thinking process more easily. This corresponds to the study of Rau and colleagues (2012, 2015), which shows that multiple external representations can significantly enhance students' learning. Similarly, a study on the advantages of dual representation in (Ainsworth, 2006), showed that text paired with graphical representation leads to better learning than text alone. Therefore, a graphical platform is required to facilitate learners in constructing their thinking processes. This leads to the questions: '*What should be an appropriate format for representing their thinking processes*?'.

However, in both strategies learners basically take actions following instructions, which is passive learning. We therefore consider activities to promote an active state of learning. We use the benefit of an observable representation of a thinking process in that can be shared with others. By assigning the role of inspector to the learners, they then have a chance to observe different ideas from peers' works and reflect on their thinking processes indirectly from those works to make a comparison. For example, if a learner has a high performance and is a very confident learner, he may use his strategy as an initial standard to review others' works, and if he has a low performance and is not a confident learner, when he sees others' complete works, he may reflect on how others completed their works and could he use the same strategy to do so? This engages them to learn more deeply (Nakano, Hirashima, and Takeuchi, 2002). Moreover, by providing them an environment to discuss and work together, it creates opportunities to share and they can be engaged in a discussion to take responsibility for their own learning (Gokhale, 1995). Nevertheless, it is not easy to accomplish learning through massive collaboration in the classroom, as certain conditions must exist that allow such activities to be conducted successfully. These are: the existence of a common goal, positive interdependence between peers, coordination and communication between peers, individual accountability, awareness of peers' work and joint rewards. In what follows, we analyze the importance of each of these conditions (Szewkis et al, 2011). *How do we facilitate collaboration and commenting effectively in our case*? Therefore, we propose the framework, CIRCLE, which consists of three reflective learning supporters: (i) an interactive Q/A environment, (ii) observable representations and (iii) a collaborative platform.

To investigate the effects and conditions of the CIRCLE framework more deeply, in this study, we make an investigation to see how to design a metacognitive training system while preventing cognitive load and over-reliance on supports by implementing it in the system to train metacognition on MWP solving, called MathReflect. The details are revealed in the next section.

3. MWP Solving is Compatible to CIRCLE Framework

3.1 MWP Solving and Metacognition

Mathematical word problem (MWP) solving is a basic topic in many other higher-level educational fields. It is based on a textual description of a real word context, which requires students to apply their mathematical knowledge. However, according to reports from many standard tests (e.g. TIMSS, PISA, etc.), many students had difficulties in learning MWP solving. The main difficulty that students encounter in solving MWP is they cannot construct a problem model of a context by making inferences from the text (Jacobse & Harskamp, 2009). It was revealed by Schoenfeld (1992) that it is because they rarely take the time to monitor and regulate the use of cognitive strategies, even if they understand the calculations embedded in the word problem. This causes them to skip or misinterpret information from the problem and choose inappropriate solutions. The skills to monitor and regulate the use of cognitive strategies are necessary to help students to structure their problem solving process in MWP as well as in any other learning domain.

3.2 Key Features of MWP for Implementation

As previously mentioned, MWP solving is the topic that many students have difficulties in. However, due to its nature and structure, we found that there are beneficial features of MWP solving to support the implementation of the CIRCLE framework. The key features of MWP solving to support the CIRCLE framework are:

- *Complexity of the solution process*: this feature is appropriate for *interactive Q/A environment* in which the reasonably complex solution process provides a way to reflectively analyze the thinking process.
- *Explicit form of solution process*: this feature is beneficial for designing *observable representation* of the thinking processes to support the monitoring and representation framework to externalize/reflect/regulate problem solving process.
- *Many explicit operators at each step*: this feature promotes regulation of criteria to select one operator from operators and supports a discussion environment, which can raise a discussion topic in the *collaborative platform* from different selections.

4. MathReflect Enhancing Metacognitive Skills in MWP Solving

To investigate the effects of the framework, CIRCLE, in facilitating metacognitive skills in a real classroom, we implement the CIRCLE framework in MWP solving by developing a system called MathReflect, which is composed of three sessions: Q/A sequence (QA-sq) session, inferential diagram (InDi) session and peer's inspection (PI) session, corresponding to the CIRCLE framework. The explanation of each session in the system and the philosophy of its design are expressed in these following subsections.

4.1 Q/A sequence (QA-sq) session

QA-sq session is designed to be consistent with the two components of the CIRCLE framework, 'interactive Q/A environment' and 'observable representation'. The training goal of this session is to enhance students' abilities to create/select metacognitive questioning in order to regulate/reflect on their thinking processes and to be aware of their self-difficulties during problem solving process. By the end of the session, the QA-sq of a student's thinking process to solve MWP is created. QA-sq is a sequence of questions and answers to acquire information on how to accomplish the solution of a given MWP, see the figure 2-(c).

As mentioned, students' learning performances are subjective. Not all students are ready to learn metacognition. Creating QA-sq is designed to facilitate students to think or to remind them of what they are thinking at the moment they are solving MWP. The figure 2 shows the interface of the QA-sq session. A student participates in the common task of constructing QA-sq of MWP solving through these following main operations.

- Creating questions. A question created by a student reflects what s/he thinks. Does s/he be aware of what s/he thinks during solving problems? Can s/he use questions to monitor/regulate her/his solving process?
- Choosing questions. This is an option to assist students when they are having difficulty in creating questions by themselves. They can choose or imitate the questions from the provided list. This will help them to become familiar with making questions to plan/monitor their problem solving processes.

- Requesting for step-by-step questions. If they are in a confused state and have no idea how to go forward, the system can deliver to them a sequence of questions in a step-by-step manner to support their basic ability to solve the problem before promoting their metacognitive skills.
- Answering the questions. Students have to find answers to the questions they created or selected to accomplish their tasks.
- Requesting for hints. This to reduce cognitive load for some students.

The system records a learner's behavior in the system, such as the number of times asked for a hint, time taken to answer the question, and log file of editing. These data are used to classify learners. In this study, learners can be classified into 4 levels according to their proficiencies as shown below. Moreover, these data are used to analyze the sessions to improve the framework. Role assignments of the first session are shown in the second column of the table 1. QA-sq from this session is used as material for discussion in the PI session, see the section 4.3. The criteria of creating good QA-sq are as follow:

Criteria for Good QA-sq

1. The sequence leads to a problem solution.
2. Qs and As in the sequence have to be consistent and well-ordered.
   2.1 Each question has to contain a correct answer.
   2.2 No question early in the sequence requires information from a question later in the sequence to answer.
3. The sequence contains necessary questions.

Learners are classified into 4 groups by performance:

1. *High Performance Students*: a student who can solve a problem and perfectly complete a QA-sq.
2. *Average Performance Students*: a student who can solve a problem but cannot complete QA-sq by himself. However, by using hints he can accomplish the task.
3. *Low Performance Students*: a student who cannot solve a problem and cannot make a QA-sq even while using hints but can follow the correct QA-sq for realizing how to solve the problem.
4. *Out of Scope*: a student who needs special support.

Table 1: Roles assigned in each session in MathReflect system.

Roles	**QA-sq session**	**InDi session**	**PI session**
Student	• Create QA-sq	• Draw InDi	• Assess peers' works • Discuss with group members to improve the solution. • Revise solution
System	• Facilitate students to create QA-sq • Record students' behavior • Classify students' performance • Deliver the instructions and warning messages	• Deliver the instructions and warning messages	• Assign group members • Deliver assessment criteria and commenting categories • Deliver the instructions and warning messages
Teacher	• Provide learning materials: problems, background knowledge, hints, metacognitive questions	• Give suggestions	• Support discussion
Expert	• Provide data input format • Learning classification criteria	• Design representation format	• Design interaction criteria

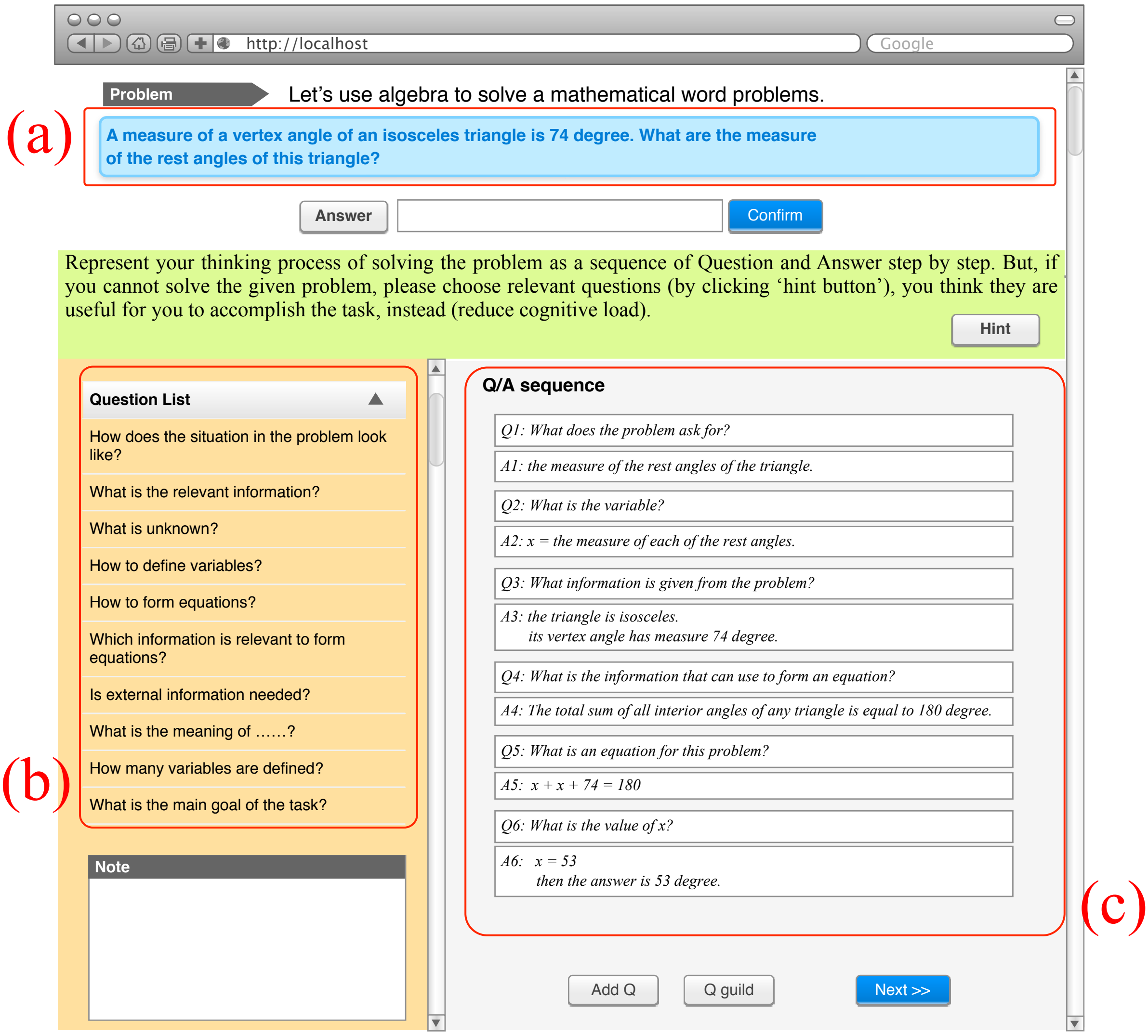

Figure 2. The interface of QA-sq session.

4.2 Inferential Diagram (InDi) session

Koedinger (1991) revealed that perceptual inferences might appear easier than symbolic inferences because people practice them more often than symbolic inferences. InDi session is obviously consistent with 'observable representation' in the CIRCLE framework. Here, we promote students' abilities to externalize/reflect on/regulate their problem solving process using graphical representation. We would like to use graphical representation to emphasis the reasons for asking the questions in the first session, for example, the problem goal node is compatible with the question 'What does the problem ask for?' in QA-sq. By analyzing MWP, we realize that in any MWP, it is composed of observable elements ([problem goal], [given information]) and hidden elements ([problem sub-goal], [hidden information]). Consider the example problem in figure 2-(a), the command sentence, 'What are the measures of the rest angles of this triangle?', is a [problem goal]. The informative sentence, 'A measure of a vertex angle of an isosceles triangle is 74 degrees.', is [given information]. The prerequisite task to from an equation is [problem sub-goal]. The knowledge to form an equation, 'sum of interior angles of any triangle = 180°', is [hidden information]. Therefore, we can facilitate learners to construct representation of the thinking process to solve MWP as shown in the figure 3. An arrow line is used to link between 2 directly related nodes. For example, the problem goal '*Find the measures of the rest of the angles of the triangle*' directly lead to define the unknown value as the variable *x*, or the information '*the triangle is isosceles*' can infer to the information '*the triangle has 2 equivalent angles*'. Text-box button is used to state the reason or intention to a connection, such as, we can infer the information '*the triangle has 2 equivalent angles*' from '*the triangle is isosceles*' using the property of an isosceles triangle. At the end of this session, InDi is created. It will be used to support PI session together with QA-sq as materials for collaborative discussion to reduce the implicitness of the human thinking process and make it easier to indicate and comment on any errors in the solutions.

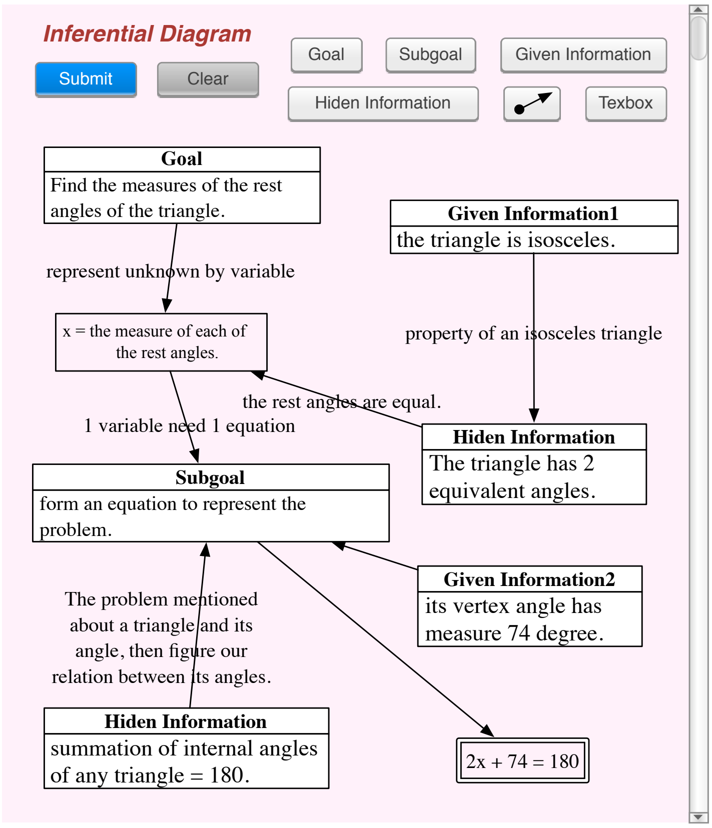

Figure 3. The graphical representation-constructing platform.

4.3 Peer's Inspection (PI) session

The last session is consistent with the 'collaborative platform' of the CIRCLE framework. In this session, we aim to foster rational discussion and reflection on the students' problem solving processes by letting them communicate via representations of their MWP solving processes as a role of a commentator, which enables them to internalize what they are reflecting on in the ongoing learning process.

The main strategy of this session is to assign an inspector/commentator role to the students, this encourages them to proceed from a passive to an active state of thinking. In this implementation, we also investigate the conditions that enable an effective discussion. In the forth column of the table 1, role assignments in the PI session are distributed. In the PI session, the system firstly divides students into groups of three based on performance. The students in each group are of different performances. The students would have been classified into these performance groups by the system using the criteria mentioned in the section 4.1 which is using the information from the QA-sq and InDi sessions. In the group, each student has tasks to individually inspect their peers' works (QA-sq's and InDi's) of the same group. To inspect QA-sq, students will be reminded of the "*Criteria for Good QA-sq*", mentioned in the section 4.1, as an assessment rubric. Moreover, to facilitate the students in making comments and providing feedback to peers, the system supports them by providing comment types as follow:

i. *Insert-comment*: this is used to suggest to peers to add more necessary elements,
ii. *Remove-comment*: this is used to suggest to peers to remove unnecessary elements,
iii. *Modify-comment*: this is used to suggest to peers to edit/adjust incorrect elements,
iv. *Question-comment*: this is used to ask open-ended questions about peers' works.

After the individual inspection, all members in the group participate in the real-time discussion platform as shown in the figure 4. In this state, all members in the group have the same task to revise the inspected works simultaneously on the shared-work space. Each student shares their opinion among members in the same group about their reasoning on their solution that corresponds to their inspection. They then have to make an agreement that all inspected works are the final opinions for the group members to revise their works to resubmit to the system. A teacher can monitor and assess any discussions to support/encourage weak discussions.

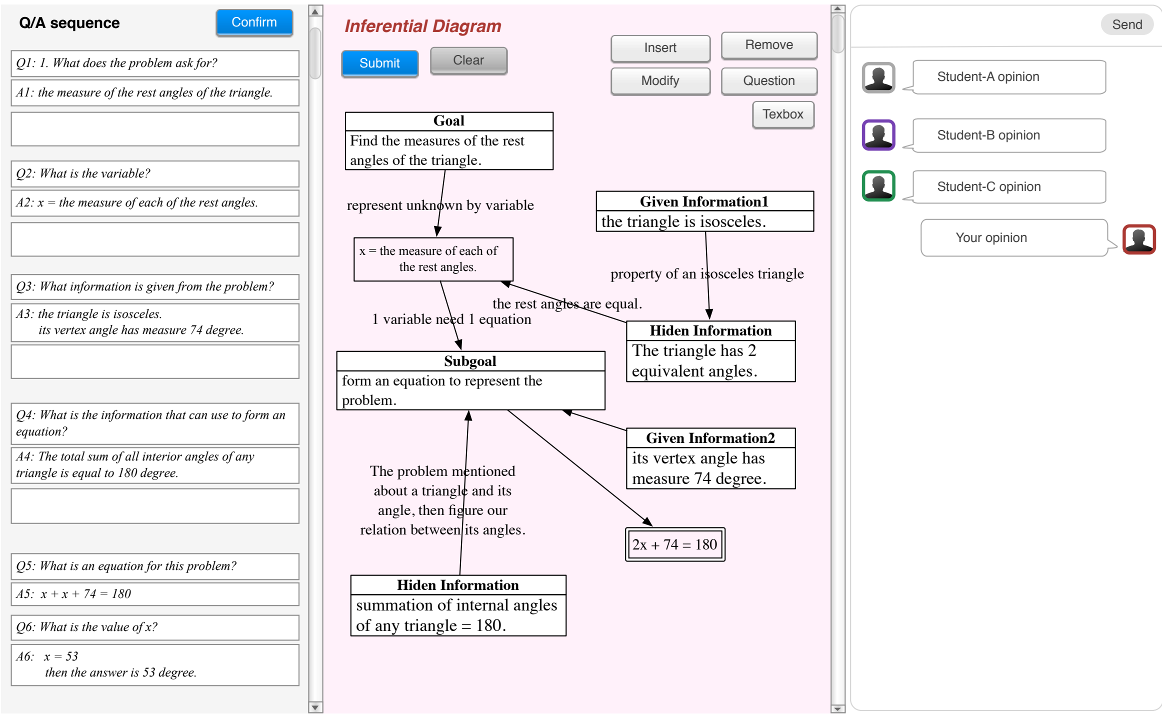

Figure 4. The interface of PI session.

5. MathReflect: Learning Procedure

5.1 Procedure

The subjects of this study are approximately 30 seventh grade Thai students. In the study, they are tasked with solving MWP problems (in the Thai language) individually by following the instructions from the system. Then, the system separates them into groups of three. The teacher observes and encourages her students while they are working individually and the teacher can participate in their collaboration by guiding and encouraging them via her computer.

In this implementation, students participate 8 times (2 times a week) in learning activities and each activity takes approximately 80 minutes. All participants attend the first period (80 minutes) to familiarize themselves with the tools by watching a video and then the teacher explains the usage of the system and allows them to use the system to solve the first problem by following the teacher. In this period, the students are provided the same MWP in order to help them become familiar with the activity and the system.

In the second period, the students are asked to solve one problem by practicing all 3 sessions of MathReflect. In this period, the students get similar MWPs in the same group in order to enhance their learning and thinking. Similar MWP's are MWP's with similar concept and structure, but have different context and numbers. This is to avoid them feeling bored with the same problems, which may reduce the benefits of peer tutoring. These are examples of similar problems.

- MWP 1: *You had some cookies and milk for breakfast this morning. The total number of calories of your breakfast is 232. Each cookie has 25 calories and a bottle of milk has 57 calories. How many cookies did you have for breakfast?*

- MWP 2*: Susan paid $240 to have her house decorated. The materials used to decorate the house cost $115, and service was charged at $5 an hour. How many hours was the house worked on?*

In the second period, they do activities by following the instructions from the system and they can access the instruction video on demand. The teacher is an observer and a supporter upon their request. The time allocation of this period is as follows: They have 5 minutes to read and thinking about whether can they solve the problem; 15 minutes to construct a QA-sq; 10 minutes to create InDi; 10 minutes to inspect their peers' works; 20 minutes for group discussion; and the last 5 minutes to revise their works and resubmit. In this period, the teacher's role is emphasized in the discussion activity.

In the third and fourth periods, 5 problems are assigned, two of which are processed in MathReflect and the other three using tradition methods with notes for extra explanation. The time allocation of the third and fourth periods are provided as follows: In the third period, 10 minutes to read and decide whether can they solve the problem; 30 minutes for constructing QA-sq; 20 minutes for creating InDi; 20 minutes for inspecting their peers' works. In the fourth period, 10 minutes for re-inspecting peers' works; 30 minutes for group discussion; 5 minutes to revise their works and resubmit, and 45 minutes for individually solving 3 problems and showing the working-out in detail with sketching notes.

The process of the third and fourth periods will be repeated for the fifth-sixth and seventh-eighth periods.

5.2 Data collection

To examine how students develop their metacognitive skills in our proposed environment, data collection includes students' QA-sq and InDi, pre- and post-tests, log files of their interaction with the system (e.g., button click, time duration), commented works, discussion logs and interviews. Because analysis of the training metacognitive skill process is a complicated and multi-sided task, a mixed summative evaluation method (Lazakidou & Retalis, 2010) will be considered for this study. Firstly, a pre- and post-test of three MWP's are used in order to acknowledge the students' learning. Secondly, semi-structured interviews (Yang, Cheng & Chan, 2014) will be conducted to interview the teacher and the high, average, and low performance students. These qualitative data will be transcribed, coded, categorized, and compared in multiple ways for emerging meaningful themes. Additionally, one of the most common trace methodologies to analyze students' cognition while participating in a CSCL activity is the content analysis of the students' notes posted in the system (Pifarre & Cobos 2010), and thus, the comments and feedback together with students' messages and actions during their collaborative activity will be used throughout the data analysis of this process.

6. Conclusions and Future Work

In this paper, we explain a conceptual construction of our proposed framework, named CIRCLE. The CIRCLE framework is a framework to facilitate metacognitive skills, which consists of three reflective learning supporters: an interactive Q/A environment, observable representations of thinking processes and a collaborative platform. Using each component, leaners are engaged/encouraged to reflect on their self-cognitions in harmoniously different ways. Firstly, using reflective questioning to alert and externalize the thinking process out loud. After that, the thinking process is captured into an observable format, which is easier to manage. In addition, the observable representation of their thinking process can be shared and discussed which can offer more idea options to broaden learners' perspectives. In the paper, the proposed framework, CIRCLE, is implemented in the MWP solving domain via the proposed system, named MathReflect, which is planned to be applied in the real classroom to gain more practical information to improve and shape up the framework. In summary, MathReflect is a system to facilitate metacognitive skills in solving MWP. It uses the concept of the CIRCLE framework in its implementation. We therefore expect it to enhance learners' competencies in metacognitive skills in solving MWP.

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