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Analyzing a Practical Implementation of Training Metacognition through Solving Mathematical Word Problems

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Abstract: The aim of this paper is to demonstrate an analysis of a practical implementation of Computer-Supported Multi-Reflective Learning Model via MWP (CRLEM) by developing a web application system, called MathReflect. MathReflect shows that it can encourage a learner to reflect on their thinking process and familiarize with utilization of metacognitive questioning by graphical representation and meta-level discussion stimulation integrated with delivering appropriate metacognitive questioning at the right time and events. Especially for this study, a questionnaire for classifying a learner who has gained Seed Skill to become a self-regulated learner (Q-L2SRL) is developed and integrated with the data collected from the system as the system evaluation method.

Keywords: Metacognition, self-regulated learner, math word problem, peer assessment, collaborative learning, reflective learning

1. Introduction

From my past experience as an educator and a mathematics teacher, solving mathematical word problems (MWP) is like a bitter pill for students. This is consistent with reports from many standard tests (e.g. TIMSS, PISA, etc.) that many students have difficulties in learning MWP solving. The main difficulty that students encounter in solving MWP is to 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. 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 involved in metacognitive skill. We found that this is an advantage feature of MWP solving which could be utilized as a medium to train metacognition instead of using a real life problem, which is ill-defined/unstructured. Due to complexity/implicitness of metacognition combining with an unstructured problem, it might be quite complicated and could cause frustration in novice learners.

The goal of training metacognitive skill is to help learners 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 difficulties to achieve their tasks. To become a self-regulated learner, a skill in which a learner induces themselves to comprehend their own cognition is required. We call this skill, "***Seed Skill to become a self-regulated learner***". 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 (Duangnamol, Supnithi, Suntisrivaraporn, & Ikeda, 2015). To reduce the difficulties of training metacognition, cognitive targets from thinking processes in working memory are shifted to observable thinking processes (Kayashima, Inaba & Mizoguchi, 2005). The observation found in (Akanda, 2013) showed that reflecting on self-cognition enables learners to link their professional development to practical outcomes and to refine/broaden the understanding of what counts as useful activity. A new and promising research subject thus may be assessing the effects of computer environments, which combine cognitive content with metacognitive support. Such metacognitive support can be designed in several ways, for example by using intelligent tutoring systems, educational multimedia systems, virtual agents, metacognitive hints, and so on (Nakano, Hirashima, & Takeuchi, 2002; Jacobse & Harskamp, 2009). In our research, we propose ***Computer-Supported Multi-Reflective Learning Model via MWP*** (CRLEM | kɜːlɛm |). It is composed of three components: Interactive Metacognitive Q/A environment, Representation Format of thinking processes and Meta-level Collaborative Discussion platform. Then, we implement the system, called MathReflect, to see how CRLEM supports learners to use intrinsic comprehension of metacognitive questioning to acquire Seed Skill to become self-regulated learners.

2. MathReflect System

We have developed a web application system, MathReflect, as an environment for CRLEM. MathReflect can be accessed via this URL (http://mathreflect.com). Figure 1 shows the system architecture. The system is composed of three components and a database. Corresponding to CRLEM, the three components are Interactive Metacognitive Q/A module (ImQA module), Thinking Representation editor (TR editor), and Metacognitive Collaborative Discussion platform (MCD platform). ImQA module has Metacognitive-Responding Agent (MrA) to automatically deliver metacognitive questions and encouragement messages and to receive responses from a learner. TR editor is composed of two components: QAS constructing toolkit (QAS is a sequence of questions and answers to acquire information to accomplish the solution of MWP) and InDi composing toolkit (InDi is a diagram showing a flow of information and its source/reason to be composed for accomplishing the solution of MWP). MCD platform is composed of two components, which are Peer Inspection toolkit and Collaborative Chat toolkit. MrA works in relation with both TR editor and MCD platform. It is active throughout a learning session to stimulate metacognitive learning atmosphere. In the next section, the learning architecture of the system and its flow of teaching/learning are explained.

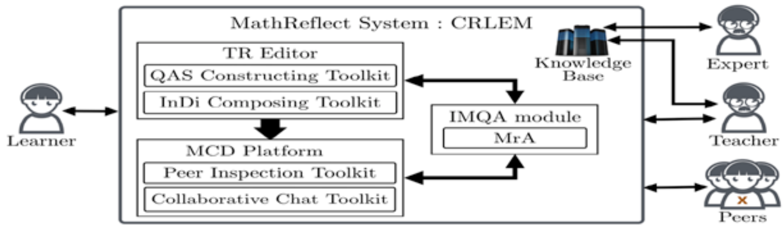

Figure 1. Architecture of MathReflect system: CRLEM

3. MathReflect User Interface

To demonstrate how MathReflect works in practice, we review each phase in the system by traversing on its UI. MrA always appears in the bottom left of the active window, as shown in Figure 2. The interface of MrA has a *message display window* to deliver metacognitive messages to a learner, a *timer* to show time duration that a learner has spent in the session, and a *text-input box* with an *accept/send button* to get feedbacks from a learner. The following subsections provide more detail and examples to demonstrate the use of the system in each phase.

3.1 Overview Phase

In the first phase, the Overview Phase, MetaQ's are used with our Description of Advantage Use of Metacognition (DAUM) and an example of QAS/InDi for introducing a learner to metacognition to provide them with meta-understanding of MWP solving. DAUM is composed of short explanation/definition of the relevant skills of a self-regulated learner and examples of questions to activate/encourage those skills. This content is shown in the Introduction Page to a learner when they start the Activity session. MrA provides time for the learner to read and make an understanding of the content, before delivering a metacognitive massage/question, e.g., "*Please state your aim for studying MWP solving*", to initiate the learner to realize their goal to studying MWP solving.

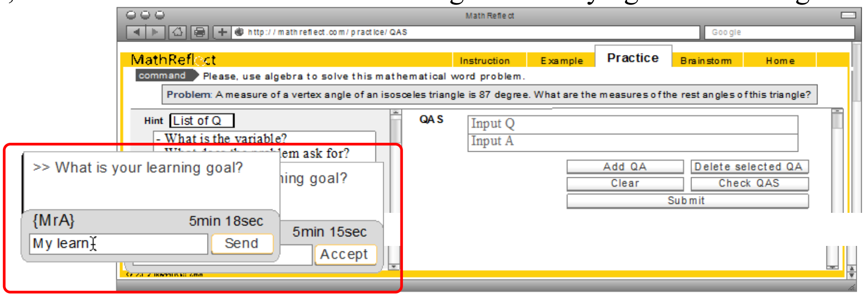

Figure 2. Web interface of MathReflect at QAS Constructing Page

3.2 Practice Phase

In the Practice Phase, MetaQ's are used when the learner solves MWP by constructing QAS/InDi. Applying MetaQ's while constructing QAS/InDi helps them to shift their meta-level thinking to base-level thinking to foster them to acquire meta-understanding of MWP solving.

This MWP for figure 3 and 4: *A measure of a vertex angle of an isosceles triangle is 87 degree. What are the measures of the rest of the angles of this triangle? (Use algebra to solve the problem)*

Q1: What does the problem ask for?
A1: the measures of the rest angles of the given triangle.
Q2: What information is given from the problem?
A2: the triangle is isosceles. its vertex angle has measure 87 degree.
Q3: How to solve the problem?
A3: By algebraic approach. We need
Q4: What is the variable?
A4: x = the measure of each of the rest angles.
Q5: What is the information that can use to form an equation?
A5: The total sum of all interior angles of any triangle is equal to 180 degree.
Q6: What is an equation for this problem?
A6: x + x + 87 = 180
Q7: What is the value of x?
A7: x = 46.5 then the answer is 46.5 degree.

Figure 3. An example of QAS

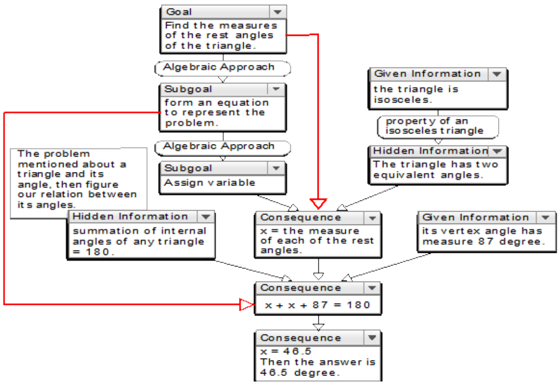

Figure 4. An example of InDi

Figure 3 shows an example of QAS. QAS is a sequence of questions and answers to acquire information on how to accomplish the solution of a given MWP. In QAS Constructing Page, see Figure 2, there are QAS constructing toolkit and QAS constructing support hint. QAS constructing toolkit is for facilitating a learner to form QAS. It is composed of, Input box: a pair of text inputs (one for a question and the other for its answer), Add button: for adding input box, Delete Selection button: for deleting a selected input box, Clear button: for clearing the work space, Submit button: for submitting the finished QAS into the system, Check Answer button: for checking correctness of ongoing QAS before submission. The following are possible responses from the system when the learner click on Check Answer button: 1) there is inappropriate order of sequence, 2) there is insufficient information contained, 3) there is irrelevant question contained, 4) there are n-wrong answers, and 5) the solution is incomplete. QAS constructing support hint is provided in the left column of the QAS Constructing Page. It is used to scaffold the learner to familiarize with vocabulary utilization of self-questioning in solving MWP. The following are the hints we provide for a learner:

1. *List of possible questions/answers: contains a list of questions/answers with some irrelevant questions/answers in random order.*
2. *Filter only relevant questions/answers: contains a list of relevant questions/answers in random order.*
3. *Make proper order of the list of questions/answers: contains a list of relevant questions/answers in proper order.*

Figure 4 shows an example of InDi. It is a diagram showing a flow of information and its source/reason to be composed for accomplishing the solution of MWP. InDi is composed of Information Node (in a rectangle)—to show information required, Information Tag (in top of each

Information node)—to indicate the source of the information (there are six tag options: Goal, Sub-Goal, Given Information, Hidden Information, Result, and Others), Order Link (black arrow)—to show consecutive order in which the information used, Reason (in a dashed rectangle over certain Information nodes)—to indicate why information applied, and Sequential Link (red arrow)—to illustrate the result which needs information that is not consecutively linked. To composing InDi, the learner has a task to selecting appropriate Information Tags and Reasons from the provided lists for existing information to make InDi complete. Before submitting InDi, the learner can check its correctness by clicking Check button. The system can report his/her number of wrong tags/reasons via pop-up window.

3.3 Peer Support Phase

In the last phase, the Peer Support Phase, MetaQ's are applied to make the learner reflect on the performance of others and what they had done during inspecting peers' works to prepare them new vocabulary and information in collaborative discussion. This phase makes the learner gain awareness of self-improvement on MWP solving. This phase is composed of two sub-phases: *Peer Inspection* phase and *Metacognitive Collaborative Discussion* (MCD) phase.

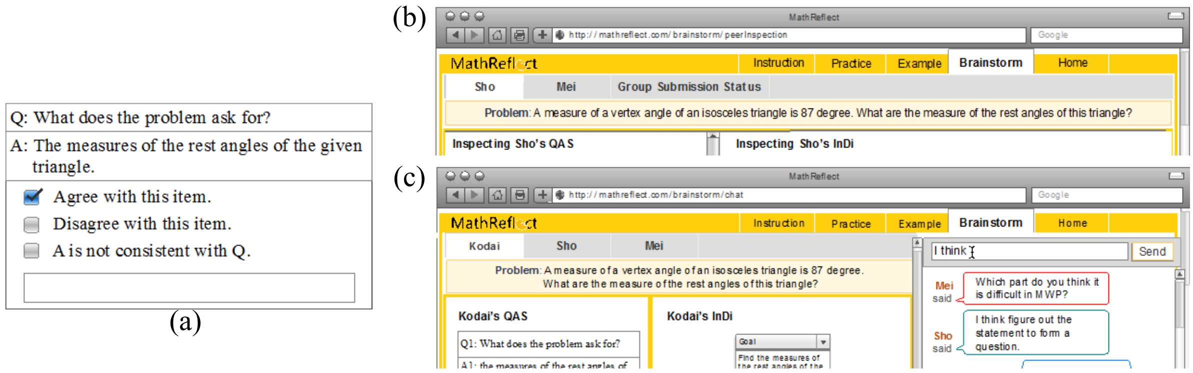

Figure 5. (a) QAS Inspecting tool, (b) Peer Inspection Page, and (c) Discussion Page

Figure 5(a) shows the tool in the Peer Inspection Page. To inspect QAS, the learner can: (1) agree with a pair of QA, (2) disagree with a pair of QA, (3) disagree with an answer and suggest another answer, (4) swap the sequence, and (5) add an extra pair of QA. To inspect InDi, the learner can reselect *Information Tag/Reason*. Moreover, the system also informs which hints other members have used and the number of times they have clicked the check button. The learner cannot step into the final phase, the MCD phase, unless all of the group members, including themselves, have submitted the inspected QAS/InDi. The submission status can be checked in the Group Submission Status link, see Figure 9(b).

Figure 5(c) shows the Discussion Page. This page contains the Discussion space at the right side of the page. The rest of the page is provided for displaying the inspected QAS/InDi of the members as a part of materials for discussion. The learner can access the inspected QAS/InDi of each member by clicking its owner name under the menu bar. In this phase, the learner can communicate with the group members in the Discussion space to enquire information to answer metacognitive questions from MrA to complete the session.

4. Analyzing MathReflect

4.1 Sampling Procedure

In this study the scope of our subjects are grade-9 Thai students who are confused and do not recognize/realize their difficulties in solving MWP. This is to differentiate those who have gained improvement using MathReflect from those who are self-regulated learners. To sample the subjects for our study, first, a teacher gives a lecture on general knowledge of MWP solving using algebra in traditional method to students. Then, those students are screened by a MWP solving test. The students who failed the MWP solving test are selected to take Meta-Understanding in MWP Solving Questionnaire (MUMSQ). The questions in MUMSQ are shown as follows:

(1) *Why can't you solve the problem?*

(…) *I don't know!* (…) *I have no idea!* *or Express your reason: ……………………*

(2) *What is difficult for you that makes you fail to solve MWP?*

(…) *I don't know!* (…) *I have no idea!* *or Express your reason: ……………………*

The students who cannot express their reason are selected as the subjects in this study.

4.2 Procedure of Training Metacognition with MathReflect

To train metacognition with MathReflect, our training program has 6 periods. Each period has 90 minutes. In the first period, a teacher hands on the program syllabus to all subjects, then, the 90 minutes of the period is divided into 20 minutes for the *Overview Phase*, 20 minutes for the *Practice Phase*, 45 minutes for the *Peer Support Phase*, and the last 5 minutes for MWP-quiz. In the 2^{nd} – 6^{th} period, the 90 minutes of each period is divided into 12 minutes for the *Overview Phase*, 20 minutes for the *Practice Phase*, 45 minutes for the *Peer Support Phase*, and the last 13 minutes for MWP-quiz.

4.3 Analysis of Practical Implementation of MathReflect

In this section, we show how to analyze the change of a learner after studying MWP solving with MathReflect to indicate whether the learner can perform MetaQing skill to acquire:

1. Meta-understanding of MWP solving (MU) and
2. Awareness of self-improvement on solving MWP (AS).

To analyze the change of a learner after studying MWP solving with MathReflect, MU is considered in 3 dimensions: self-understanding, task understanding, and process understanding. Consequently, AS is considered in the same dimensions. More precisely, each dimension is considered in sub-categories as follows:

- *Self-understanding* [S] is composed of 5 categories: (i) attitude in studying MWP solving, (ii) goal of studying MWP solving, (iii) motivation in studying MWP solving, (iv) self-restriction in studying MWP solving, and (v) background knowledge for studying MWP solving.
- *Task understanding* [T] is composed of 4 categories: (i) principle/structure of MWP solving, (ii) knowledge required for studying MWP solving, (iii) factors influencing the complexity of MWP solving, and (iv) application/benefit of studying MWP solving.
- *Process understanding* [P] is composed of 4 categories: (i) MWP solving process order, (ii) obstacles during solving MWP, (iii) timing in solving MWP, and (iv) concentration during solving MWP.

The following scenario is used to demonstrate how to analyze the change of a learner. Due to a privacy issue, we name a volunteer JJ. JJ is a grade-9 student of a school in Sisaket province, Thailand. He failed our MWP-test. However, he was willing to be a volunteer in our study. This may imply that he would like to improve himself on MWP solving. The selected scenes happened in Overview Phase 1^{st} round (OP1), Peer Support Phase 1^{st} round (PP1), and Overview Phase 3^{rd} round (OP3).

(Overview Phase: 1^{st}) after 5 minutes on the Introduction Page, MrA asked JJ, "*How well do you understand what you read*". Then JJ answered, "*I am not sure*!". MrA responded, "*It's ok just move on*", and delivered another statement, "*Please state your aim for studying MWP solving* [MQ1]". JJ seemed confused. He then asked the teacher how to reply. The teacher suggested that JJ read the program syllabus. JJ answered, "*To understand the fundamental strategy in solving MWP using algebra and be able to apply it in daily life* [A1]".

(Peer Support Phase: 1^{st}) MrA suggested a discussion topic, "*What are learning goals of the others*?[MQ2] *How is it important to set up learning goal*?[MQ3]". One member in JJ's group, AA, asked in the discussion space, "*What is your learning goal*?[MQ4]". JJ replied, "*MrA asked me a similar question, I answered MrA by using the learning objective from the syllabus* [A2]". The other member, ZZ, replied, "*I want to master solving MWP. How about you AA?*[A3]". AA replied, "*I agree with both of you*". JJ raised a question to peers, "*Why is it important to set up the learning goal*?". ZZ replied, "*I think if we know our goal we can plan for it* [A4]". AA replied, "*It helps me to focus my attention on the study* [A5]". JJ replied, "*Oh.. I never thought about it before! I agree I agree* [A6]".

(Overview Phase: 3^{rd}) MrA raised a similar statement again, "*Please state your goal for learning MWP solving* [MQ5]". This time JJ replied, "*I want to be able to master modeling MWP* [A7]".

The selected scenes demonstrate the analysis of the *goal of studying MWP solving* category in *Self-understanding* dimension, denoted as [S-ii]. The system encouraged JJ to [S-ii] by MQ1. By asking the teacher, he showed that he was confused. In PP1, JJ showed evidence confirming that he had no idea about [S-ii] at first, although, from the teacher's hint he had a rough idea that following the learning objective could be set as a learning goal, as shown in A2. Moreover, the group members' responses in A3-5 could enhance his understanding about [S-ii]. In OP3, he changed his answer to the same statement using his own opinion, A7, which reflected his understanding in [S-ii].

Besides collecting data from the system, we also use a Questionnaire for classifying a learner who has gained Seed Skill to become a Self-regulated learner (Q-L2SRL) as a part of the evaluation method for MathReflect. Q-L2SRL has been especially developed for our study. The items in Q-L2SRL were developed to cover all categories in all 3 dimensions of MU and AS. As a result, there are 26 items in Q-L2SRL. Q-L2SRL is shown in this link, https://goo.gl/forms/RjL9y867tvIFmrMR2.

From the case of JJ, in comparing between the beginning and the end of the program, JJ improvement in MWP solving can be significantly detected. His performance in MWP solving is increased, observed from MWP-quizzes. He can solve a seen problem or similar MWP more comfortably. From his log data collected from the system, there is ample evidence to show that JJ has gained meta-understanding in MWP solving. He expressed his opinion more often into his responses/answers in the late period of the program. Corresponding with Q-L2SRL, his score for MU and AS are 2 and 1.85 (from the full score of 3), respectively. This implies that he has gained the Seed Skill to become a self-regulated learner.

5. Conclusion and Future Works

By implementing MathReflect, it is shown that CRLEM has a potential to support a learner to gain Seed Skill to become a self-regulated learner. The system can stimulate the learner to get used to performing metacognitive questioning skill to acquire meta-understanding of MWP solving and awareness of self-improvement on solving MWP. The system works by encouraging a learner to reflect on their thinking process and familiarize themselves with utilization of metacognitive questioning by graphical representation and meta-level discussion stimulation integrated with delivering appropriate metacognitive questioning at the right time and events. In the future work, we would like to expand our subjects to English- and Japanese-speaking students. Moreover, we plan to generalize our learning model, CRLEM, to be independent of MWP solving.

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References

Akanda, A. (2013). Learning and development question and answers. In A. Akanda, *The Practicalities of Human Resources: FOR HR Practitioners' - Fresh Perspective* (pp.369-385). Bloomington: Author House.

Duangnamol, T., Supnithi, T., Suntisrivaraporn, B., & Ikeda, M. (2015). Facilitating Metacognitive Skill using Computer-Supported Multi-Reflective Learning: Case Study of MWP Solving. *The 23rd International Conference on Computers in Education* (pp. 124-133).

Jacobse, A.E, & Harskamp, E.G. (2009). Student-controlled metacognitive training for solving word problems in primary school mathematics. *Educational Research and Evaluation*, 15(5), 447-463.

Kayashima, M., Inaba, A., Mizoguchi, R. (2005). *What Do You Mean by to Help Learning of Metacognition?*. Proceeding of Artificial Intelligence in Education, 346–353.

Nakano, A., Hirashima, T., & Takeuchi, A. (2002). A Support Environment for Learning by Describing Problem Map. *International Conference on Computers in Education* (pp. 119-123). Auckland: IEEE Computer Society.

Schoenfeld, A. H. (1992). Learning to think mathematically: Problem solving, metacognition, and sense-making in mathematics. In D. Grouws (Ed.), *Handbook of research on mathematics teaching and learning* (pp.224-270). New York: MacMillan.