Metacognitive Skills: A Solution in Chemistry Problem Solving

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Abstract. One of the skills needed in the 21st century is thinking skills including metacognitive skills. Many studies showed that undergraduate students who used metacognitive skills are more successful in learning. This study aims to illustrate using metacognitive skills as a solution in chemistry problem solving and undergraduate students' respond. The design used One Group Pre-test and Post-test Design. The subject of this study was the undergraduate students of chemistry class academic year 2019/2020 as many as 31 people. To obtain the profile data of metacognitive skills and undergraduate students' respond through an essay test, interview, and questionnaire. Research data were analysed by quantitative descriptive. The results showed that: (1) performance of metacognitive skills of undergraduate students has high category in chemistry problem solving on each indicator. The indicators were goal setting, identify the known knowledge, determining the learning strategies, monitoring the relevance of the known knowledge with learning strategies, monitoring the goal achievement in the making conclusions, and evaluating the process and thinking outcomes, and (2) most of the undergraduate students are pleasant to join to this learning activity. Based on the results of this study, metacognitive skills can be used as a solution in chemistry problem-solving.

1.   Introduction

Metacognitive skills are mental abilities that consciously be arranged, controlled, and examined for their thinking processes. Moreover, metacognitive skills are higher-order thinking skills regarding ways of thinking that involve cognitive processes [1]. Metacognitive skills have three components, namely planning skills, monitoring skills, and evaluation skills [2]. Metacognitive skills are very important to be empowered in the education system because they can empower high-level thinking and increase academic success [3; 4]. Metacognitive skills and undergraduates' student achievement have a positive relationship [5]. Undergraduate students who have good metacognitive skills will have good cognitive learning outcomes too.

The development of metacognitive skills is important because they can develop their learning atmosphere to be more meaningful, develop thinking skills, engage in problem-solving processes, and choose strategies to improve cognitive performance in the future [6; 7]. Therefore, learning metacognitive skills needs to be empowered.

In fact, learning of colligative solutions has not been able to empower metacognitive skills and improve the cognitive learning outcomes of chemistry undergraduate students. The metacognitive skills were still low be shown by planning skills about 57.68% of undergraduate students. It means that they cannot set goals and plan strategies for problem-solving. Moreover, the monitoring skills were about 66.52% of undergraduate students and means they have not been able to relate known knowledge with

strategies used to solve problems. The evaluation skills were about 72.39% of undergraduate students that means difficult to evaluate the process and the results of their thinking.

In fact, learning of colligative properties matter has not been able to empower metacognitive skills and improve the cognitive learning outcomes of chemistry undergraduate students. The metacognitive skills were still low be shown by 57.68 % of undergraduate students who could not set goals and plan strategies for problem-solving (planning skills). Moreover, 66.52% of undergraduate students have not been able to relate known knowledge with strategies used to problem-solving (monitoring skills) and 72.39% of undergraduate students difficult to evaluate the process and the results of their thinking (evaluation skills).

The low metacognitive skills of undergraduate students have an impact on learning difficulties and errors in understanding colligative properties matter. This error occurs in understanding the concept of vapour pressure related to the effect of the presence of solutes, sub-microscopic images of the process of evaporation of electrolytes and non-electrolytes associated with differences in their boiling points. Moreover, misunderstanding also occurs in the concept of osmotic pressure, and the relationship between the increasing boiling point and the decreasing in freezing point, molar mass and Van't Hoff factor. This is consistent with research findings that learning difficulties and misunderstandings occur in the concept of the colligative properties of solutions [8]. Based on this, the empowerment of metacognitive skills must be carried out on undergraduate students, so the undergraduate students can plan, monitor, and evaluate their learning outcomes to find out deficiencies and can make improvements to achieve better learning outcomes.

Empowerment of metacognitive skills in chemistry done by applying undergraduate students' ability in solving chemistry problems. The steps of problem-solving covering understanding the problem, make a plan, do the plan, and look back at the results obtained [9]. The steps in the chemistry problem-solving process are in accordance with metacognitive skills, namely planning skills done by undergraduate students with making a plan, monitoring skills did when undergraduate students do the plan, and evaluation skills by a look back at the results obtained. This meant the ability in solving chemistry problems important to mastering by the undergraduate student and being a provision in dealing with academic problems and daily life. Eggen and Kauchak also emphasized the importance of problem-solving ability who stated that problem-solving ability independently are long-term goals and undergraduate students need to have the ongoing experience to achieve this goal [10]. The statement reinforced by an opinion that ongoing experience, undergraduate students more developed, both in cognitive affective as well as psychomotor aspects [11].

The importance of metacognitive in problem-solving is shown from the results of research that with metacognitive skills, university students can focus more on solving problems and can manage the learning process and solve scientific problems correctly so as to improve undergraduate student academic achievement [12]. Humans who have high metacognitive skills will do problem-solving better [13]. Through metacognitive skills, each undergraduate student can plan and manage time, choose the right strategy and provide understanding in learning, and monitor the progress of learning by reflecting the use of strategies, effective solutions, and self-efficacy of each undergraduate student in problem-solving [14].

Chemistry problem solving with metacognitive skills in this study is the ability of university students to develop cognitive strategies and involve awareness to regulate their own cognitive activities that include awareness in planning, monitoring, and evaluating, as well as being aware of their use in chemistry problem-solving. The problem presented in this study is a non-routine chemistry problem. The non-routine chemistry problem in question is a problem to find/solve questions related to chemistry problems that do not have specific procedures so that further thought needed so that they can immediately find a method/procedure to solve the problem.

Based on the description above, the objectives of this study are: (a) Describe the performance of undergraduate students' metacognitive skills in learning chemistry problem solving on each indicator. The indicators were setting goals, identifying known knowledge, determining learning strategies, monitoring the relevance of existing knowledge to the learning strategies used, monitoring the achievement of objectives in making conclusions, and evaluating the process and results of thought, and (b) Explain student responses in teaching and learning.

Method

This research used the One-Group Pre-test Post-test Design and the difference between the initial test and the final test is to be the effect of the treatment. The research was conducted in the undergraduate students of the chemistry department of Universitas Negeri Surabaya academic year 2019/2020 as many as 31. Samples taking using a purposive sampling technique by selecting undergraduate students who have low metacognitive skills based on pre-research data.

Metacognitive skills measured through essay tests and undergraduate students' respond measured using the questionnaire. All instruments validated with validity test and reliability test. The essay tests and the university students' response questionnaire sheet have been validated tests by the experts. Test instrument reliability was done by using the KR-21 formula. The question of metacognitive skills consists of 12 items for the colligative properties of solutions. The indicators of the metacognitive skills are goal-setting (P1), identification the known knowledge (P2), determining the learning strategies (P3), monitoring the relevance of knowledge which has been owned with learning strategies are used (M1), monitoring the achievement of the goal in the making conclusions (M2), and evaluating the process and outcomes of thinking (E) [15]. Scoring of metacognitive skills obtained from the scoring rubric of metacognitive skills integrated with essay form written tests adapted from Corebima [16]. The metacognitive skill scored changed to a scale of 100, and the value obtained categorized according to the level of attainment of its metacognitive skills. The levels of achievement and these categories are very high (85 - 100), high (70 - 84), medium (55 - 69), low (40 - 54), and very low (0 - 39). The analysis for metacognitive skills used percentage, while the interviews and questionnaire result descriptively.

3.   Result and Discussion

Undergraduate Chemistry students at Universitas Negeri Surabaya carry out the process of chemistry problem-solving in the material of the colligative properties implemented the stages of planning skills, monitoring skills, and evaluation skills. The measurement of problem-solving process by 12 essays test items consisted of 6 items for planning skills, 4 items for monitoring skills, and 2 items for evaluation skills.

3.1 Planning Skills

Illustration of achieving undergraduate students' metacognitive skills for problem-solving in planning skills that includes goal setting (P1), identifying known knowledge (P2), and determining learning strategies (P3) indicators shown in **Figure 1**.
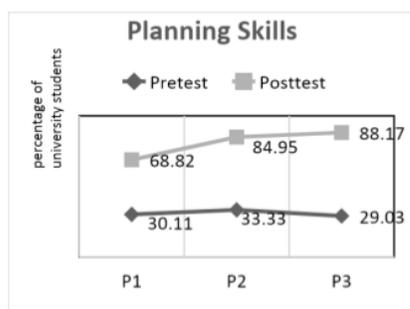
Figure 1. Percentage of Achievement of Each Indicator in Planning Skills

The results of planning skills for P2 and P3 indicators are high and very high because 70% of undergraduate students already have a value of ≥ 70, except for P1. The metacognitive skills of most undergraduate students' in problem-solving at the planning skills stage before learning is at a very low category level. These abilities increase to high and very high after learning, especially on indicators identify known knowledge and determine learning strategies in problem-solving. This fact shows that

after learning, most of undergraduate students have been able to empower metacognitive skills at the planning skills stage, especially in indicators identifying known knowledge and determining learning strategies in problem-solving of colligative properties of solutions.

However, on the goal-setting indicator, some of the undergraduate students are less able to set goals according to the problem that solved. This can occur when undergraduate students determine the goal of problem-solving by analysis the experimental images measuring osmotic pressure at 300 K using 1M glucose solution (B) in a small tube that is put into pure water (A) and separated by a semipermeable membrane/osmosis membrane producing a pressure of 24.6 atmospheres (**Figure 2**)
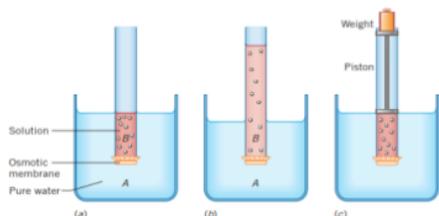

Figure 2. Measurement of osmosis pressure

Some of the undergraduate students still have errors in determining the goal of problem-solving based on the phenomenon in **Figure 2**. The goal of problem-solving should be to determine the relationship between osmotic pressure and the concentration of solution and temperature. The purpose of problem-solving will direct undergraduate students to evaluate the performance carried out in developing concepts, namely in measuring osmotic pressure using Van't Hoff's opinion where osmotic pressure is directly proportional to concentration and temperature, $\Box$ V = n_2 R T with $\Box$ is osmotic pressure at T temperature from a solution containing n_2 mole of solute in a solution.

$$\frac{\pi \cdot V}{T} = constant = 0,082 \ L \ atm \ K^{-1} \ mole^{-1}$$

The undergraduate student's error in setting goals based on the results of the interview was that he could not understand the function of the semipermeable membrane and the theories proposed by Van't Hoff.

An initial indicator of metacognitive skills in planning skills is the ability to set learning goals based on phenomena (P1). This planning skill is in accordance with Jbeili's opinion, that the component of the cognitive arrangement of planning skills includes goal setting, activating relevant resources, and choosing the right strategy [17]. Another indicator is the skill of identifying known knowledge in observing phenomena (P2) and determining strategies to solve problems (P3). Both indicators in the planning skills stage have shown that all of undergraduate students have understood the knowledge and strategies needed to solve problems. This is in accordance with the positive response from undergraduate students stating that learning of the colligative properties of solutions can help in understanding material and practising metacognitive skills to identify the known knowledge through phenomena and determine strategies to problem-solving (Figure 1). One of them asserted:
"The phenomenon presented has been able to empower metacognitive skills and ease in understanding the material."

The need for planning skills in chemistry problem solving is in accordance with the opinion which states that undergraduate students must be able to solve problems by identifying knowledge already possessed and relevant to the phenomenon [18]. This confirmed by Rysz that when someone sees a problem in a phenomenon, it would indirectly have to identify relevant knowledge about the problem [19]. This is also consistent with the opinion that the selection of strategies to be used, learning resources that need to be collected, how to start, and which ones should be followed or implemented include planning skills in problem-solving [20].

3.2 Monitoring Skills
Problem-solving in monitoring skills in the pre-test and post-test shown in **Figure 3**. The overall results of monitoring skills have a very high category. The metacognitive skills of most undergraduate students in problem-solving at the monitoring skills stage before learning have very low categories. This

ability shifts to a very high level after learning. This fact shows that after learning, most undergraduate students have been able to empower metacognitive skills in the monitoring skills stage in problem-solving of the colligative properties of solutions
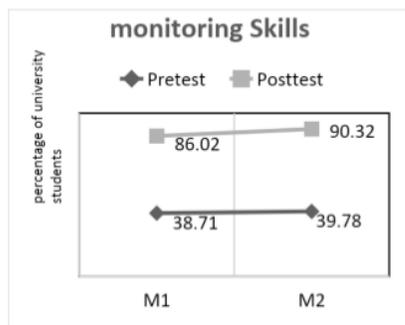

Figure 3. Percentage of Achievement of Each Indicator in Monitoring Skills

At the stage of problem-solving shows that undergraduate students monitor the relevance of knowledge already known and the learning strategies design used. The need for monitoring skills supported by statement Rickey and Stacy's that undergraduate student who applies metacognitive skills in good monitoring skills can increase success in problem-solving [21]. Likewise, the findings of the Fresenborg and Kaune study revealed that metacognitive skills in monitoring skills are the control of the problem-solving process [22]. Another statement that monitoring activities are direct awareness of how we carry out cognitive activities [20] and the results of the study found that a monitoring activity is a manifestation of the dimensions of goal development or to-do list [23]. This finding is in line with the opinion that metacognitive skills in internal undergraduate students are the key to controlling the success of learning situations [24].

Undergraduate students do problem-solving regarding the difference of freezing point of glucose solution and silver nitrate solution, as follows:

a. Analysis the phenomenon about glucose solutions (non-electrolyte substances) containing 1.80 g glucose (molar mass 180 g mole^{-1}) and a solution of silver nitrate (electrolyte substance) containing 1.70 g silver nitrate (molar mass 170 g mole^{-1}) each dissolved in 160 g of water. The silver nitrate solution ionizes as much as 83%. If Kf of water = 1.85 ^{0}C/m
b. Setting goals and identifying knowledge that is known based on phenomena
c. Determining the learning strategies problem solving
d. Implementing the task completion plan based on the planned problem-solving strategy

$$m_{glucose} = \frac{mole}{kg \; of \; solvent} = \frac{g}{molar \; mass \; x \; kg \; of \; solvent} = \frac{1,80 \; g}{180 \; g \; mol^{-1} \; x \; 0.160 \; kg} = 0.0625 \; m$$

$\Delta T_f = K_f . \; m = 1.85 \; x \; 0.0625 = 0.117$
$T_f = 0 - 0.117 = - 0.117^0C$ (freezing point of glucose)

$$m_{silver \; nitrate} = \frac{mole}{kg \; of \; solvent} = \frac{g}{molar \; mass \; x \; kg \; of \; solvent} = \frac{1.70 \; g}{170 \; g \; mol^{-1} \; x \; 0.160 \; kg} = 0.0625 \; m$$

$$\alpha = 0.83 = \frac{i-1}{2-1} \rightarrow i = 1.83$$

$\Delta T_f = i . \; K_f . \; M = 1.83 \; x \; 1.85 \; x \; 0.0625 = 0.212$
$T_f = 0 - 0.212 = - 0.212^0C$ (freezing point of silver nitrate)

3.3 Evaluation Skills

Problem-solving in evaluation skills at the pre-test and post-test shown in **Figure 4**. The majority of undergraduate students have metacognitive skills in chemistry problem-solving at the evaluation skills stage before college learning is at a very low category level. This ability only shifted to quite high after college learning. This fact shows that after the learning process, the majority of undergraduate

students still do not optimally empower metacognitive skills at the evaluation skills stage in problem-solving of the colligative properties of solutions.
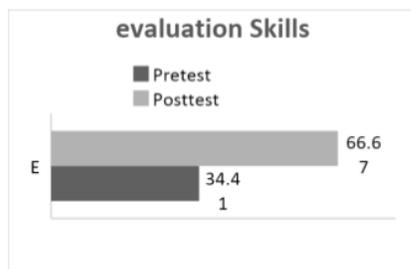

Figure 4. Percentage of Achievement Indicator in Evaluation Skills

According to the researchers' notes, some of the undergraduate students were less able to evaluate the known knowledge through the problem-solving process. This happens when undergraduate students have been able to determine the freezing point of silver nitrate and glucose solutions, but they cannot explain why to use that thinking because they do not understand the difference between the electrolyte and non-electrolyte solutions. Undergraduate students must be able to explain that in a solution of silver nitrate and glucose with the same molality and different freezing points because there are dissolved particles. The decrease in the freezing point of AgCl solution is greater than the decrease in the freezing point of glucose because AgCl is an electrolyte that has an ionization rate that causes a decrease in the freezing point of the solution is greater than glucose solution that is not ionized or no ionization rate. This is in accordance with Van't Hoff's law. According to the interview results, undergraduate students stated that they were not used to evaluating results or concepts that found using theoretical and empirical studies. This is a consistent response from undergraduate students as explained below.

"The implementation of learning from the colligative properties matter that has been followed is good and interesting, but it is difficult to evaluate the process and results of thinking using concepts that have been learned in problem-solving process."

In evaluation skills, undergraduate students must be able to evaluate their knowledge, learning objectives, learning strategies in building concepts and reflection assessment in the process of thinking/learning. This is consistent with the opinion that reflections carried out at the evaluation skills stage can be in the form of objectives that have been achieved, which learning strategies are more efficient, assess how learning strategies are applied in other contexts, and respect oneself after learning or completing assignments. In evaluation skills, undergraduate students train to think about what they had been learned [23]. So, the application of evaluation skills in learning can help to evaluate undergraduate students' way of thinking to be better in the future [25].

3.4 Undergraduate students Response
The interesting lectures obtained from the responses of undergraduate students using the response questionnaire, and the results presented in **Table 1**.

Table 1. Undergraduate Students' View in Response

Ease in practising metacognitive skills
a. Goal setting
b. Identification the known knowledge through phenomena
c. Determining the learning strategies or thinking
d. Monitored the relevance of the known knowledge, goal achievement, learning strategies, and the implementation of strategies
e. Evaluated the relevance of the known knowledge, goal achievement, and learning strategies that have been used

Based on **Table 1**, the tendency of undergraduate students to respond to lectures has a high category. Meanwhile, most of undergraduate students expressed interest in taking lectures on other material and other subjects by applying metacognitive skills. Nevertheless, the lowest response (63.64%) found in terms of evaluating the relevance of the known knowledge, goal achievement, and learning strategies that have been used (**Table 1**). This was consistent with college student comments as described below.

"The lectures implementation on colligative properties of solution that have been followed were good and interesting, but it was difficult to evaluate the relevance of the known knowledge, goal achievement, and learning strategies that have been used in problem-solving."

In line with this comment, another undergraduate student also comments as follows.

"The activity of planning skills, monitoring skills, and evaluation skills have not used to do before, so often forget to be done, for example in setting learning goals and communicating the results of self-evaluation."

4. Conclusion

Based on the objectives and results of the research can be concluded that: (1) performance of metacognitive skills of undergraduate students has high criteria in chemistry problem solving on each indicator. The indicators were goal setting, identify the known knowledge, determining the learning strategies, monitoring the relevance of the known knowledge with learning strategies, monitoring the goal achievement in the making conclusions, and evaluating the process and thinking outcome, and (2) most of undergraduate students are pleasant to join to this learning activity. Based on the results of this study, metacognitive skills used as a solution in chemistry problem-solving.

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