Students’ regulation of cognition in physics problem-solving

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Abstract. In physics education, the regulation of cognition becomes an essential activity for students in solving problems. The way students solve the problem by presenting the answer is not enough to show the steps of regulation of cognition completely. To discover the steps fully, this research focused on the way students solve a problem through thinking aloud. Via this technique, students could reveal their thinking pattern in solving the problems. Based on the exploration of preliminary study, three of 68 students were selected purposively as the participants to represent the low, middle, and high level of physics problem-solving skills. Each student was given a test about heat transfer of some system states by thinking aloud. The result showed that all participants passed all steps of regulation of cognition, although they worked at different speeds. Students of the middle and high level of problem-solving skills could plan fast and effectively. The lack of confidence when doing monitoring mostly was done by the middle-leveled student. However, the high-leveled student needed diagrams to ensure the chosen concept in solving the problem. Meanwhile, the low-leveled student presented the answer in a different version, was correct in guessing, but incorrect on physics concept during monitoring.

1. Introduction

It has been commonly known that metacognition skills have a uniqueness in predicting learning outcomes [1]. There are two main components of metacognition skills: knowledge about cognition and regulation of cognition [2]. These two components will build metacognition skills that play a role in improving learning through regulated performance [3] and conceptual understanding [4].

Regulation refers to one’s activities in monitoring and adopting a strategy for carrying out the planning [5]. Regulation of cognition leads to the students’ tendency to recognize the situation in which this regulatory strategy is used, then to apply the strategy, rather than merely to focus on self-reflection in learning skills and effectiveness in strategy [6]. Regulation of cognition activities covers three main categories of coverage: planning, monitoring, and evaluation [7]. Whitebread et al. [8] named regulation of cognition as metacognitive regulation and divided it into four stages: planning, monitoring, control, and evaluation.

As metacognition skills, regulation of cognition is commonly used in multiple domains, e.g., reading and problem-solving. In problem-solving, regulation of cognition has five stages: planning (determining the objectives and strategies used to solve problems), information management strategies (specific ways that can be used to solve problems effectively), monitoring (checking the use of strategies on a regular basis when completing problems), debugging (a strategy to minimize misunderstandings and work), and evaluation (evaluating results) [3,9].

Related to the stages of regulation of cognition, several studies have been conducted. These studies were conducted at several age levels of the subject. Molenaar & Chiu [10] researched sixth graders of
primary school. Research with the subjects of classes 3-9 was done by Spreling et al. [11]. Study at a university level conducted by Filho & Yuzawa [12], Lee [13], and Mihalca, et al. [14].

Research at the secondary school level was conducted on eleventh and twelfth graders as research subjects conducted by Nielsen, et al. [15]. Students worked in groups when making field trips to solve problems. The instrument used is the Metacognition Baseline Questionnaire and other data obtained through sound recording. Another study at a secondary school level was also conducted to 141 students by Sungur & Senler [16]. This quantitative study used the Metacognitive Awareness Inventory (MAI) to find out the students’ regulation of cognition. The results showed that the debugging stage and information management strategies were mostly used by students than the other three stages (planning, monitoring, and evaluation). The selection of MAI as an instrument in cognitive regression research on domain problem-solving is not appropriate because MAI is included in the instrument for off-line assessment.

The on-line method was employed during the students solved the problem [17] and referred to the actual skill while solving the problem, so this method is more appropriate. Also, preliminary studies that had been implemented indicated that students' self-assessment questionnaire scores were not significant to map the students’ cognitive skills in completing the task. Think aloud is one of the online methods that can be used with the limitations of respondents as a consequence. The data through thinking aloud were more detail so commonly used in qualitative research [18]. This study focused on how students solve problems using their regulation of cognition through thinking aloud. The limited number of respondents could be used as an advantage in exploring each respondent’s cognitive regulation to be mapped in the stages of regulation of cognition.

2. Method
This research was a case study with three respondents. The respondents were selected purposively based on tests in preliminary studies of 68 students of class XI who had studied heat transfer topics. In the preliminary, the students were given a test about Heat and Temperature topics. The three selected respondents represented low (S1), moderate (S2), and high (S3) levels based on problem-solving ability. Besides, they were chosen purposively with excellent communication ability. Among the three respondents who had similar cases, they could not show the whole stages of metacognition skills, especially in the regulation of cognition.

An adapted test of heat transfer [19,20] was used as a problem that to be resolved by the respondents via thinking aloud (figure 1).

![Student’s experiments in the scientific laboratory to examine the thermal equilibrium. He does this activity:](image)

Cup A contains 100 grams of water and cup B contains twice as much water. The water in both cups was initially at room temperature. Then, the water in cup A was heated to 75 °C, and the water in cup B was heated to 50 °C. When the water in both cups was cooled down to room temperature, he guesses that cup B has more heat transferred than cup A. Is his guess correct?

**Figure 1.** Problem-solving question.

The problem was presented with some clues that could help the students to solve the problems with clear stages. The problem was translated into the Indonesian language before being solved. This problem can be solved using the concept of heat transfer through several conditions. Video recording was utilized to record the students’ activities during thinking aloud. The transcript of this video recording became the research data analyzed by the sequential analysis [21]. The transcript loads the dialogue between the
researcher (R) and the respondents (S1, S2, and S3). The data were grouped based on what activities they were doing and classified based on what steps they were running.

3. Results and Discussion
The respondents solved problems individually at different times and durations. The respondents’ activity recorded by the video recorder in transcript form showed several stages of the respondents’ cognitive regulation in solving the problem. All respondents were managed to do the planning well. They could find the vital information contained in the problem and write it in the symbol of the magnitude of the physics along with the value of physics unit (S1-the low-level student & S2-the moderate level student), as well as in physics only (S3-the high-level student). The next planning stage, determining the purpose could be done well by the three respondents with different physical quantities. S3 wrote the heat with consideration of valuable information that she found, mass and temperature ($Q = m \cdot c \cdot \Delta T$). Meanwhile, ‘heat transfer’ was written by S1 and S2 according to the problem, $Q = m \cdot c \cdot \Delta T$, while S3 added the Black’s Principle with $Q_{\text{release}} = Q_{\text{gain}}$.

After planning, all respondents debugged to find the value of room temperature that had not been shown in the problem but needed to solve the problem. They used a mobile phone to find the value of room temperature in general (20-25 ºC). At this stage, they also did information management strategies by choosing a room temperature of 25 ºC to facilitate the calculation easily. After planning, all respondents debugged to find the value of room temperature that had not been shown in the problem but needed to solve the problem. They used a mobile phone to find the value of room temperature in general (20-25 ºC). At this stage, they also did information management strategies by choosing a room temperature of 25 ºC to facilitate the calculation easily.

In the process of monitoring through evaluation, each respondent had different ways of expressing it. Monitoring began when the respondent started running the selected strategy to solve the problem. The evaluation process was carried out when evaluating the results. These two stages will be discussed separately from each respondent.

3.1. The low-leveled student (S1)
After a relatively long process of planning (including debugging and information management strategies) compared to the other respondents, S1 used the strategy chosen to solve the problem. At first, S1 was looking for the room temperature in general through a mobile phone. Then, S1 started by calculating the temperature change ($\Delta T$) and dividing the temperature change by mass for glass B.

\[ \Delta T = \frac{m_2}{\text{mass of glass B}} \]

R: “What is the unit of energy?”
S1: “Joule”
R: “How about this (pointing to the ‘$m_2/\Delta T$’ calculation)?”
S1: “Oh, I see”
R: “Is it right?”
S1: “No.”

Here, S1 had no reason when he wrote $m_2/\Delta T$. S1 did debugging, rechecked the problem, and found the new strategy. The researchers were lured with questions about the units of magnitude asked for the problem, namely energy. Later, the formulation $Q = m \cdot c \cdot \Delta T$ was used to calculate the heat in glasses A and B when each glass was heated from the average temperature (figure 2), the value $Q_A = Q_B = 5000c$ J. Furthermore, S1 compared between the two heat, $Q_A:Q_B = 1:1$, and he believed that it was true. However, the result of this comparison was used to conclude that the statement in question was wrong.
3.2. The middle-leveled student (S2)

After writing out the strategy chosen during planning, \( Q = m \cdot c \cdot \Delta T \). S2 wrote the concept of the handover of heat as \( Q_A = Q_B \). In contrast to both colleagues, S2 wrote room temperature as an unknown variable of value. Initially, the room temperature in glass A symbolized \( x \), while the space temperature in glass B symbolized \( y \) (figure 3a). Then, he converted both into \( x \). However, S2 replaced the temperature changes to numbers after checking and realized that the temperature of the two glasses was at the same room temperature (figure 3b).

After checking the answers, S2 was not sure of the answer, then he did the debugging by asking. S2 realized that the mathematical calculation he was working on was not enough to answer the purpose of the problem.
R : "Do you know the problem’s plot?"
S2: "Heem..., yes, Miss."
R : "Okay. Is your concept correct?"
S2: He glanced, then turned to the researcher. "Don't know, wrong? Eh, isn't that right?"
R : "What is Q?"
S2: "Q (is) heat, energy, its mass influences. ΔT also influence. It means that I am lack my concept. Oh, that means the initial condition is lacking?"
R : : "Yes."
S2: : "Owww... yes, it is wrong, isn't it, Miss?"
R : : "Okay, repeat from the first step, use this paper (rive a new sheet)."
As performed by S1, S2 only calculated the heat that occurred when the two glasses were heated from room temperature, at first. With this new understanding after debugging, S2 calculated each of the heat that occurred in glasses A and B when heated from room temperature and returned to room temperature. The new calculation results were used to answer the purpose of the problem. The result was used to claim the problem statement. S2 found that the Q of glasses A and B had the same value as his conclusion.

3.3. The high-leveled students (S3)
The concept of \( Q_{\text{release}} = Q \_\text{gain} \) that selected by S3 was used to calculate. After entering the value of physics, S3 corrected her steps and was unsure of the count. S3 was debugging by looking at the sample questions and asking for the questions.
R : "What does transfers the energy?"
S3: "The water in the glass, to the temperature of the outside environment."
R : "So, can you mix glass A with B?"
S3: "No."
R : "Then, what are you going to do?"
S3: "Oh yeah that means I have to count one by one, Miss?"
S3 realized the Black’s Principle was not suitable to be used in solving the problem. By looking back at the known physics of matter, S3 discovered a new strategy by counting the calories separately by \( Q = m \cdot c \cdot ΔT \). As doing by two other colleagues, S3 also only counted the heat in one condition. When the glass was heated from room temperature \( Q_A = Q_B = 5c \) was obtained (figure 4).

![Figure 4](image_url) The S3’s answer at the initial process.
Figure 5 A picture of several conditions contain of the problem that illustrated by S3.

S3 debugged again by asking, and she was encouraged to draw the events contained in the problem under all conditions (Figure 5). Figure 4b shows some of the conditions experienced by glass A and B completed with physical quantities in each condition. S3 could calculate the heat in each condition along with the transfer if it was experienced by each class, then used to answer the purpose.

S3: “Then, it means the transfer of energy, it means from condition one to condition two to condition three, so Miss?”

R: “Yes.”

S3: “$Q_A = m_A \cdot c \cdot \Delta T$
$= 0.1 \cdot c \cdot (75^\circ - 25^\circ)$
$= 5 \text{C}$

$Q_B = m_B \cdot c \cdot \Delta T$
$= 0.2 \cdot c \cdot (50^\circ - 25^\circ)$
$= 5 \text{C}$

$q_A = \frac{Q_A}{c} = \frac{5 \text{C}}{c}$
$q_B = \frac{Q_B}{c} = \frac{5 \text{C}}{c}$

S3: “$Q_A = 5 \text{C} + (-5 \text{C})$
$= 0$

$Q_B = 5 \text{C} + (-5 \text{C})$
$= 0$
The answers obtained by the three respondents denied the statement in the problem and were at the evaluation stage. S1 gave the reason for using the comparison he finds for glass A and B. Mathematically, the calculation done by S1 number was precise. However, there were some inaccurate procedures: not converting mass units into international units, not counting the heat transfer but only those caused by the temperature changes, not analyzing all conditions on the problem. This error resulted in the concept run by S1 was wrong, so the mathematical answer was correct because of the coincidence by the numbers. Meanwhile, the S2 and S3 did a proper evaluation. This was because monitoring was done quite frequently, thus impacting the debugging stage to measure their conviction and check answers. S2 and S3 calculated the heat in all conditions and could calculate the heat transfer that occurred. Consequently, the written conclusions could reveal the reason of why the respondent refuted the statement contained in the matter.

All respondents performed the stages of regulation of cognition well. The regulation of cognition performed by each respondent was shown through various activities. Most activities were conducted by S2, while S1 did the least active among the three respondents. S2 and S3 made some strategic changes in the monitoring process. S2 chose to do error analysis using learned concepts. Meanwhile, S3 illustrated the illustrations contained in the matter under each condition. Through this monitoring, S2 and S3 managed to find the correct concept to evaluate the statement contained in the problem. The accuracy in this monitoring had an escalating effect on problem-solving [14].

Based on these findings, firstly, the three respondents were well in planning. They obtained the information from the problem as the test as a physics variable and wrote down the variable as a symbol. By this symbol, they used the mathematical equation as their strategy to solve the problem quickly. The second, although, every stage was crucial, monitoring was the most complicated part in solving the problems. In this stage, the student was going to show his/her understanding and how well he/she run the chosen strategy when they were planning. Firstly, all respondents failed using the strategy that they planned based on the problem condition. However, the high and the moderate level students passed this step easily after scaffolding. Both respondents did well, even the moderate respondent showed his best performance during the test. The third, the debugging stage was mostly done by the respondents showing that they had lack of confidence in solving the problem.

The symbol in physics is necessary to help students using the physics equation mathematically. Improving the student’s confidence is good to enable students monitor well. Additionally, good confidence performance makes the student sure in stepping the regulation of cognition to solve problems.

4. Conclusion
Each respondent could show the stages passed on the regulation of cognition through activities in solving the problem. The respondents passed the process of problem-solving in a different time. S2 and S3 were fast in effective planning compared to S1. However, S2 and S3 tended to be longer in monitoring when solving the problem. They (S2 and S3) lacked in confidence in summarizing their findings, so the monitoring stages were a long-standing. The length of duration for this monitoring has a good impact on the results shown during the evaluation. When doing the evaluation, both respondents managed to correct the statement contained in the problem.

These findings showed the success of respondents (S2 and S3) of the regulation of cognition. Although S1 had not exceeded every stage optimally, the steps indicated by the activities of respondents can be used to familiarize students that have a consistent process for solving the problem. It could be exhibited that each student had each way of solving problems. The further research can be done on activating the activities on the stages of regulation of cognition for large samples by adjusting proper learning strategies in the classroom. Besides, research on cognition knowledge as another component of metacognition skills is required.

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6. References

[1] Stel M, Veenman M V J, Deelen K and Haenen J 2010 *ZDM Mathematics Educ.* **42** 219–29
[2] Baker L and Brown A L 1984 *Metacognitive skills and reading* *Handbook of Reading Research* vol 1, ed P D Pearson (New York: Longman) 353–94
[3] Roshanaei M 2014 *Int. J. of Learning and Change* **7** 234–58
[4] Jin Q and Kim M 2017 *A case study of children’s collective problem solving & metacognitive regulation* *Proc. Conf. European Science Education Research Association* (Dublin) pp. 2–4
[5] Orturk N 2017 *Int. J. Asst. Tools in Educ.* **4** 134–48
[6] Tock J L and Moxley J H 2017 *Metacognition Learning* **12** 79–111
[7] Schraw G and Moshman D 1995 *Educational Psychology Review* **7** 351–71
[8] Whitebread D, Colman P, Pasernak D P, Sangster C, Grau V, Bingham S, Almeqdad Q and Demetriou D 2008 *Metacognition and Learning* **4** 63–85
[9] Taasoobshirazi G and Farley J 2013 *Int. J. of Sci. Educ.* **35** 447–59
[10] Molenaar I and Chiu M M 2013 *Metacognition and Learning* **9** 137–160
[11] Sperling R A, Howard B C, Miller L A and Murphy C 2002 *Contemporary Educational Psychology* **79** 51–79
[12] De Carvalho Filho M K and Yuzawa M 2001 *The J. of Experimental Educ.* **69** 325–43
[13] Lee C B 2013 *Computers & Educ.* **60** 138–47
[14] Mihalca L, Mengelkamp C and Schnottz W 2017 *Metacognition and Learning* **12** 357–79
[15] Nielsen W S, Nashon S and Anderson D 2009 *J. of Research in Science Teaching* **46** 265–88
[16] Sungur S and Senler B 2009 *Educational Research and Evaluation: An International Journal on Theory and Practice* **15** 45–62
[17] Veenman M V J, Bavelaar L, De Wolf L and Van Haaren M G P 2014 *Learning and Individual Differences* **29**123–30
[18] Bannert M and Mengelkamp C 2007 *Metacognition and Learning* **3** 39–58
[19] Niaz M 2000 *Interchange* **31** 1–20
[20] Wattanakasiwich P, Taleab P, Sharma M D and Johnston I D 2013 *Int. J. of Innovation in Science and Mathematics Educ.* **21** 29–53
[21] Knoblauch H, Tuma R and Schnettler B 2014 *The SAGE Handbook of Qualitative Data Analysis* Video Analysis and Videography, ed U Flick (Chennai: SAGE Publications Ltd) chapter 30 435–49