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Longitudinal Study of Metacognitive Skills and External Representation of Students in the Context of Problem-Solving

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Abstract

This study aims to longitudinally describe the metacognitive skills and external representation in the context of problem-solving at Chemistry Education, Tadulako University. The qualitative study respondents were selected from a number of first year students for two consecutive semesters. Two respondents were selected based on results of selection using a metacognitive skills assessment questionnaire (MCAI) and we categorized as high and medium. Three problems were resolved by respondents at intervals of one to two weeks in each semester through a one-on-one thinking-aloud and it was followed by a semi-structured interview. Data collection was recorded using a video camera. Metacognitive skills and external representation data from the odd and even semesters were deeply analyzed. This analysis technique was carried out by examining the results of problem solving and semi-structured interviews in detail and matching them with the indicators of metacognitive skills and external representation used by both respondents. The data analysis results showed that the thinking ability of respondents with high metacognitive skills in problem solving, experienced developments over time along with the development of their cognitive regulation and external representation. On the other hand, respondents with intermediate metacognitive skills during problem solving, were relatively the same for two consecutive semesters. Therefore, teachers need to consider the use of learning strategies by taking into account the number of students who have dominant characteristics in classroom learning, in terms of metacognitive skills and external representation.

Keywords: context of problem-solving, external representation, longitudinal study, metacognitive skills, one-on-one thinking aloud, problem solving

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1. Introduction

Problem-solving is an activity carried out by someone who is directed at achieving goals using a method or strategy and requires proper mental representation (Metallidou, 2009). A person's problem-solving capabilities achievement can be measured from four components, namely; resources, heuristics, control, and belief (Yen & Lee, 2011). These capabilities are strongly influenced by the understanding of materials and a person's metacog-

nitive skills to find solutions to problems (Ijirana & Supriyadi, 2018) that will provide new knowledge, skills, and other components on the person (Fischer & Neubert, 2015). However, the incomplete use of metacognitive skills (only using planning skills, not using monitoring and evaluation), will cause a potential for failure in problem-solving (Ijirana & Supriyadi, 2018). Therefore, there are two aspects that influence problem-solving, namely the use of complete metacognitive

skills and external representation. That is why it is necessary to investigate the use of these two thinking skills in the context of problem solving.

Some findings from study on metacognitive skills in the context of problem-solving states that regulation of metacognition and monitoring of proper thinking can increase success in problem-solving, including analytical and technical problems (Rickey & Stacy, 2000; Shubber, Udin, & Minghat, 2015). This metacognitive skill has become the basic approach and strategy of students to achieve goals, organize, monitor, and modify operations in problem-solving (Metallidou, 2009). Other results also discovered that awareness of cognition, planning, monitoring, and self-checking, as well as self-assessment (self-appraisal), is a metacognitive strategy often used by students (Haidar & Naqabi, 2008) as well as self-management (Demirel, Aşkın, & Yağcı, 2015). That is why metacognitive skills contribute to student academic success.

The use of an external representation system regarding the use of diagrams in problem-solving showed that some teachers and students tended to separate diagram formulation steps from interpretation and variables identification step so that they cannot attain sufficient results (Mansyur, 2015). Problem-solving with different mental representation formats can be solved by students by compiling categories of mental representations (Ibrahim & Rebello, 2013) which can be stated externally (Metallidou, 2009). External representation functions to promote investigation, conduct reflection of alternative perspectives, solutions, and criticism, as well as facilitating the development of knowledge (Van Bruggen, Kirschner, & Jochems, 2002). Cox and Jones (2011) found that the external representation and visual thinking has the potential to create ideas and make complex issues more accessible, make the organization of know-

ledge and its synthesis easier when studying Basic Chemistry, Organic Chemistry and Biochemistry. Furthermore, the reasoning of students was more varied in certain moments and that such variability shows a productive thought process as a representation in studying electric fields in physics (Cao & Brizuela, 2016). In line with this, Ningsih et al. (2013) found that physics teachers dominantly displayed representation in verbal and algebraic formats, yet when presenting concepts, and they did not emphasize the importance of diagrams. Even more generally found that representation in learning science not only improves problem-solving abilities, but can also increase retention of related knowledge and facilitate the integration of new knowledge with prior knowledge (Cook, 2006). Therefore, in this study, the emphasis was placed on the aspect of metacognitive skills and external representation of the chemistry education students. The study was carried out longitudinally in the context of problem-solving, because this aspect is one of the indicators of the success of chemistry education students in problem solving and problem solving is needed in studying chemistry. The study will also provide an overview of increased knowledge retention and integration of new knowledge from previous knowledge possessed by students at different times.

2. Method

The study used a qualitative method focusing on the investigation of metacognitive skills and external representations in the context of problem-solving of chemistry education students. We longitudinally investigated the development of the aspects in two consecutive semesters. Description of metacognitive skills and external representation obtained from the student with different metacognitive skills was based on the results of the

screening through a questionnaire developed by Cooper and Sandi-Urena (2009).

Data collection began with the screening of students registered in the chemistry education of Tadulako University, even semester of academic year 2018/2019, with different metacognitive skills. As many as 97 students were given the metacognitive skills assessment questionnaire (MCAI). Two students who were respondents in this study with a self-assessment category having high and intermediate metacognitive skills.

The two respondents were coded R1KMT and R2KMS. These respondents were drawn from a number of students who rated themselves as carrying out metacognitive skills during problem-solving with a score of $> 80\%$ in the high category and between 60-79% in the intermediate category (adapted from Demirel, Aşkın & Yağcı, 2015).

The respondents solved two problems in a one-on-one thinking-aloud setting. The second problem was resolved one week to two weeks after the first problem was resolved. Respondents who solved problems using the same method were then interviewed at different times. The same process was repeated on the same respondents using a similar problem. Problem-solving and interview activities were recorded using a video camera.

Categorization and coding of the problem-solving and interview results were done for two aspects. The first categorization and coding were for the use of metacognitive skills. This coding involves the respondent's activities, such as; planning, monitoring, and

evaluating. The planning includes activities such as; reading, translating, setting goals, formulating problems, and making plans. The monitoring includes problem-solving activities, namely; reviewing or rereading problems, checking answers, and pausing while looking at the paper or the answer in front of the student in question. Evaluating includes the activity of following the correct way to discover the answer whether (right or wrong) and involves taking several types of steps to check the correctness of the answers (final or intermediate answers), and or the respondent decided immediately that the answer is wrong and started working again. This evaluation also includes reflection, namely whether the answers obtained makes sense or is as expected. The second categorization and coding were for the use of the representation. The coding involved respondents' activities in making external representations during problem-solving. The representations can be in the form of pictures, symbols, statements, formulas, and mathematical language (Kohl & Finkelstein (2005).

3. Result and Discussion

In the following we will present the results of one-on-one thinking aloud and interviews in the even and odd semester.

a. R1KMT

The results of the study of thinking-aloud R1KMT towards solving the problem in terms of metacognitive skills and external representation in different semesters are given in Table 1- Table 3.

Table 1. Results of Thinking-aloud RIKMT during Odd and Even Semesters when Carrying Out Problem-solving Planning.

Respondent	Even semester	Odd Semester
RIKMT	In the first minute the respondent read the problem by emphasizing certain words in the statement of the problem.	In the first minute the respondent read the problem by emphasizing certain words in the statement of the problem.
	(1) The data needed to solve this problem is the first atomic number of Sulfur 16 with Oxygen 8 atomic number of.	(1) The first step to be taken is to collect all known data, namely 1) the compound molecular mass = 30.026 grams/mol; 2) this compound is made from burning methanol in a catalytic reactor; 3) using a silver catalyst; 4) the use of compounds as cosmetic preservatives, nail hardener, fly and insect repellent and materials for making urea fertilizer.
	(2) The first objective to be achieved is how the two atoms are bound and the process is formed and determine the shape of the molecule.	(2) Then step 2 looks for what was asked (the respondent reread the problem). Here what is asked is the name of the compound and its molecular shape. To find out the molecular shape of a compound, look for its constituent elements, which is where it is (reread problem)

When the data in Table 1 is viewed from the metacognitive skills perspective and external representations, it can be described that: (1) It seems that RIKMT at different times and a relatively long time has always been consistent in solving the problem, namely used metacognitive skills in making plans. A different matter occurred when the respondent translated the problem further statement thoroughly in the odd semester compared to the previous semester, because she wrote in detail all the data in the problem statement that supports the achievement of the goal. In addition, the respondent at this stage also began writing down her problem-solving strategies step by step; (2) In both periods she also remained Consistent in stating the objectives to be achieved in problem-solving but, in the odd semester of this respondent had begun to make plans for the achievement of the objectives and even had carried out monitoring by re-reading the problem statement. This shows an increase of the respondent's prudence in making a decision from time to time; and (3) The respondent did not perform external representation both in the

even or odd semester during the planning stage. Based on these findings, it can be said that the habit of doing good planning will increase one's awareness of thinking to solve problems according to targeted goals so that in solving problem one will be more careful in planning. This finding is in line with other research findings, namely that someone who chooses the right strategy and uses known information from the problem in doing the task will lead to the right performance for someone (Demirel, Aşkınb & Yağcı, 2015; Silwana, Subanji, Manyunu & Rashahan, 2021). That good planning and monitoring is very important to help students plan how to settle problems, manage the problem-solving process and ensure that it is on the right track (Berciter, 2002). This finding also reinforces previous findings that the planning strategies identified in students in solving problems are planning, setting goals, and priorities (Yang & Bai, 2019).

Data description in the problem-solving and external representation in Table 2 are: (1) in the even semester the respondents began arranging problem-solving strategy

while in the odd semester the respondent continued her problem-solving strategies because it had been started in the previous stage of thinking. An interesting thing here is that the respondent conducted assimilation thinking activities several times by stating that "combustion reaction means involving oxygen". This showed that respondent matched the knowledge of the information received with the knowledge she had. The next assimilation activity is to write down the formula for the methanol molecule (CH_3OH) after pausing for a moment to recall the knowledge she had about methanol.

Representation of methanol into the form of a chemical symbol was done by the

respondent to make it easier to write reaction equation and predict the products produced. Another thing that was shown by the respondent was the ability to represent the results of her thoughts in the form of a reaction equation as described in Figure 1.

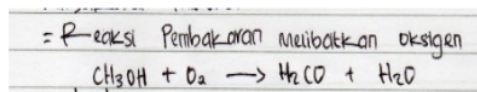
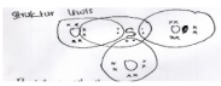
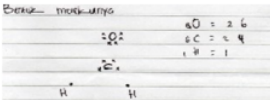


Figure 1. R1KMT's Answer Sheet For Reaction Equation

The next assimilation process at this stage is the assertion that the silver catalyst used only accelerates the reaction and does not affect the outcome of the reaction.

Table 2. Results of Thinking-Aloud by R1KMT in Even Semester and Odd Semester when Formulating a Strategy and Monitoring

Respondent	Even semester	Odd semester
R1KMT	<p>(1) The strategy used in solving this problem is that we first look for the valence electrons of each atom (the respondent writes)</p>	<p>(1) The next step is to make a reaction that occurs where a combustion reaction occurs. The combustion reaction involving oxygen and in this matter the methanol or hydrocarbons combustion in a catalytic reactor. So the methanol (the respondent thought for a while then wrote) CH_3OH; and its reaction. Oh... here there is the use of catalysts and here are the by products of water. Thus the amount of C and H on the left and right of the number is the same, namely the number C is 2 and H = 8 and O = 4. The silver catalyst here serves to accelerate the reaction rate and is not found in the reaction result.</p>
	<p>(2) To determine electron valence, the first thing to do is to make an electron configuration, the second, make the Lewis structure. The sulfur has an atomic number 16 so its electrons are on the skin; KLM has an electron number of 2 8 6 each. Next $O_8 = 2 6$</p> <p>(silent respondent) So S_{16} is valence electron 6 and O is valence electron 6. So the Lewis structure</p> 	<p>(2) After that, the next step, fourth (the respondent is silent and writes) After obtaining the reaction results, the molecular shape can be determined. Let's say this is compound data, the compound obtained was CH_2O so 6 was the atom number of C, H was 1, and O was 8. So the configuration of the electron to C is 2 and 4 and O = 2 and 6. So it can be concluded where C is the central atom with H and O, which surrounds the central atom.</p> <p>So the Lewis structure:</p> 

Respondent	Even semester	Odd semester
	<p>(3) Determine PEB and PEI to determine molecular shape. So this is O to be stable it binds electrons from S and this S also binds electrons from O to stabilize it so this is the shape</p> <p>So this is (hum) the PEB, the pair of free electrons is zero while the bound pair of electrons is 3. So the molecular shape is AX₃ (Trigonal Planar).</p>	<p>(Respondent rereads written answers)</p> <p>So it can be seen that the compound intended for the problem is formaldehyde or commonly called formalin in the form of trigonal molecular planar.</p> <p>So according to the VSPER theory the molecular form above is Trigonal Planar with 2 pairs of free electrons on the atom that surrounds the central atom and electron pair with 4 bondings.</p>

Next, in the next stage the respondent used the concept of equalizing the reaction equation by counting the number of elements involved in the reaction as in Figure 2.

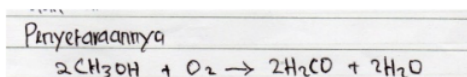


Figure 2 R1KMT's Answer Sheet for the Concept of Equalizing A Reaction

In the interview session, the respondent ensured that this reaction product was correct and one way to do that was to test the type and number of elements involved in the reaction. The activity shows that the respondent conducted regulation of cognition through monitoring while evaluating problem-solving to ensure the correctness of the results. (2) It seems that the process of thinking and representation carried out by the respondent are the same for even or odd semester. The respondents rearranged the plan with the same steps to write the Lewis molecular structure in which form was to be determined. The activity was started by making electron configurations in the form of images. A different manner was carried out by the respondent in the odd semester when she was going to make a molecular structure. There was a lack of confidence of the respondent when she was to describe the molecular structure of formaldehyde where the respondent paused for a moment then crossed it out and made a new

molecular structure. This shows that the respondent continuously monitored her problem-solving process; and (3) Different representations were made in the even semester, namely from the representation of molecular shapes to the next picture form, then to a mathematical equation form, and finally in the form of mathematical statements (Figure 3).

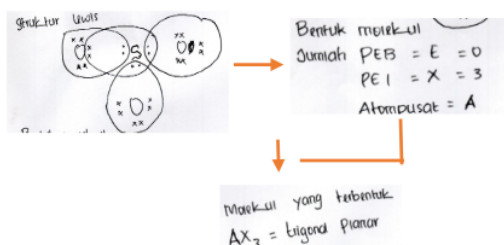


Figure 3. R1KMT's External Representation Sequence in the Even Semester

In contrast to the odd semester, representation of the shape of the molecule was expressed as a mathematical statement from a picture form as shown in Figure 4.

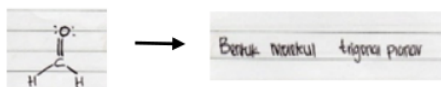


Figure 4. R1KMT's External Representation Sequence in the Even Semester

The respondent's confidence toward this result shows in the interview result that if the geometric form was like this, then it is a

trigonal planar. This indicates that there was an increase in the respondent's ability to predict molecular shapes based on the number of bonding electrons and free electron pairs of the compound in the Lewis structure. Thus, student with high metacognitive skills will increasingly develop their knowledge along with the development of cognitive

regulation. In contrast to the findings of Yanti, Amin, and Sulaiman (2018) who found that students who have multiple intelligences, in presenting information, preparing plans, and implementing plans in problem-solving, use the same representation whereas when evaluating results, using various forms of representation.

Table 3. Results of Thinking-Aloud by R1KMT in Even Semester and Odd Semester when Evaluating Problem-solving Result

Respondent Code	Even semester	Odd semester
R1KMT	So the molecule formed is AX_3 because the PEB of the central atom is missing. (read the questions then write)	This answer can be strengthened by the information that is known in the problem, which is the use of the compound in question, namely as a preservative of cosmetic products, nail hardener, fly and insect repellent, as well as making urea fertilizer. Where all of the above statements refer to formaldehyde compounds and where the formaldehyde molecular mass is also known to be 30.026 grams/ mol.

The data in Table 3 shows that the last step undertaken by respondent in the two periods was evaluating results. Evaluation skills performed by the respondent in the odd semester shows a more developed thought process compared to the even semester. In the odd semester respondent evaluated results using logical thinking skills, namely connecting formaldehyde molecules formula with relative molecular mass and its properties. This indicates that a person who is accustomed to organizing his/ her thinking to solve problems will increase his/ her awareness to convince himself/ herself in making decisions, so that mistakes in solving problems will increasingly diminish. This is in line with the findings of Rahman et. al. (2010a) which

stated that evaluation skills will allow students to reduce the mistakes made in the process of problem-solving. The same applies with the findings Veenam and Spaans (2005) which stated that metacognitive skills occur together, but it is not entirely dependent on the intellectual ability because metacognitive skills exceed intelligence as a predictor of learning performance.

b. R2KMS

The results of the study of thinking-aloud and interview in R2KMS toward solving a given problem in terms of metacognitive skills perspective and external representation in different semesters are given in Table 4 - Table 6.

Table 4. Results of Thinking-Aloud by R2KMS in Even and Odd Semester When Conducting Planning, and Monitoring

Respondent Code	Even semester	Odd semester
R2KMS	Respondent read the problem slowly (1) In solving the first problem, namely knowing the atomic number of iron is 26 and the atomic number of oxygen is 8. (2) The purpose of solving this problem determines the process of forming compounds from iron that bind with oxygen and determining the compound formula	Respondents read the problem slowly (1) The first compound formed is obtained by burning methanol, so what we need to know is the molecular formula of methanol, which is CH ₃ OH. After that we make the combustion reaction of methanol using a silver catalyst or argentum. Now the reaction is like this, then equated before combustion and after combustion In this problem it is stated that in addition to the compounds produced, water was also produced (reread the problem) Well the combustion reaction of methanol, to me, produces carbon dioxide gas and water

From the perspective of metacognitive skills, and external representations, the data in Table 4 can be described as follows: (1) it seems that R2KMS at different times and relatively long periods of time is less consistent in solving problems. Respondent in the even semester did the planning by translating the problem and stating the objectives to be achieved systematically, while in the odd semester the respondent translated the problem without stating the goal, yet she immediately formulated a strategy to solve the problem. Respondent revealed the solution to his/her problem directly by stating that the compound obtained from burning methanol is carbon dioxide gas after writing down the reaction equation; (2) It appears that respondent in this odd semester carried out assimilation thinking activities by linking new information received with the knowledge they already have. This is done by translating the word 'combustion' by presenting chemical reaction with the addition of oxygen. In addition, decision making about the compounds produced is done through equalizing the reaction equation; (3) Other activities of respondent at this stage was monitoring when performing reaction equalization by repeatedly

make an improvement through crossing out mistakes which is shown in Figure 5; and (4) Decision making by the respondent without an evaluation caused the respondent to has a chance of failing in solving problems. It is identified by the methanol combustion reaction results obtained, namely carbon dioxide.

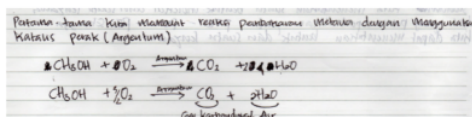


Figure 5. R2KMS's Answer Sheet in Monitoring on Reaction Equation Equalization in Odd Semester

The result of the interview showed the respondent stated that all combustion reactions must be the result of carbon dioxide. This certainly cannot be denied when methanol is completely combusted allowing carbon dioxide to be produced. But in this problem, the compound in question has a relative molecular mass of 30.026 g/mol and functions as a preservative, a fly repellent, and as a material for making urea fertilizer. If the respondent reread the problem statement and re-examined the results, this would not have happened because carbon dioxide does not have

these characteristics (a relative molecular mass of 44 g/ mol). Therefore, evaluation skills are needed in problem-solving.

The data in Table 5 shows that; (1) Problem-solving style that is done by respondents both in the even semester and odd semester both go through strategy development. In both of these time periods, the respondent showed a consistent problem-solving manner by showing the same representation, namely the picture representation into a statement, alternating between them; and (2) What was interesting about how students carried out problem-solving in the Even Semester was that they carried out monitoring against the problem-solving process that was still inconclusive, as shown in Figure 6.

It was different in the odd semester, the respondent was very sure of the answer by giving scientific explanations in each part of the solution. This finding is in line with the findings of Fitrianna, Dinia, Mayasari, dan Nurhafifah (2018) that students with high mathematical abilities have been able to present data/information from one representation into diagrams, graphs, or tables and solve problems using words or written text.

The data in Table 6 shows that the results evaluation technique carried out by R2KMS did not change from time to time. Respondent did not try to assess the problem statement when making a decision and did not re-monitor the problem-solving process, so they (she) did not realize that the molecular mass of CO₂ was not 30.026 grams/mol.

This was evident when the interview was conducted because the respondent did not try to think that the truth of the results could be tested with the relative molecular mass of carbon dioxide or its properties. Therefore, in

addition to getting used to thinking how to think about the task being carried out, insight or mastery of concepts related to the problem being solved was also required. These results indicate the need to follow up on the findings of Rahman, et. al. (2010b) stated that teachers need to be aware of the importance of promoting metacognitive development in the classroom. Ijirana (2017) stated that metacognitive skills are an important part of learning for chemistry education students, because according to Setiawan, Arisanty, Hastuti, and Rahman, (2020) greatly contribute to improving learning outcomes. Masari and Anghel (2012) found that it plays an important role in learning success and is closely related to authentic assessment and holistic learning.

Therefore, attention of teachers is required in designing learning strategies by paying attention to students in the intermediate metacognitive skills category, because this category always dominates in the classroom (Demirel, Aşkın, & Yağcı, 2015; Altındağ, 2008; Temel, Özgür, Şen & Yılmaz, 2012; Kiremitçi, 2013; Jaafar & Ayub, 2010; Duran, 2011).

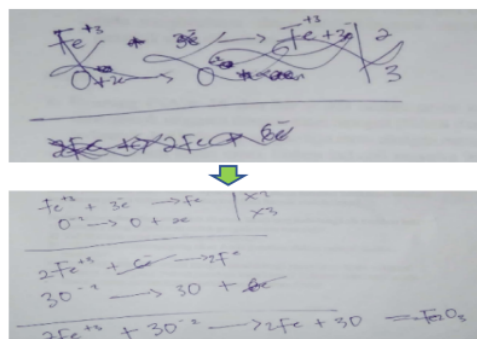
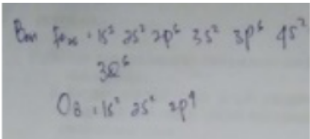
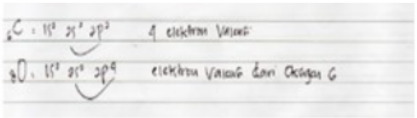
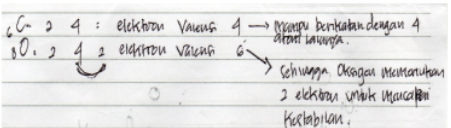
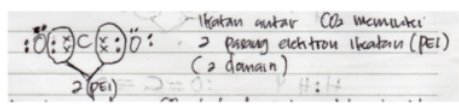


Figure 6. R2KMS's Answer Sheet in Monitoring on Reaction Equation Equalization in Even Semester

Table 5. Results of Thinking-aloud in R2KMS of Even Semester and Odd Semester when doing Planning, Monitoring, and Troubleshooting

Respondent Code	Even semester	Odd semester
R2KMS	<p>(1) The first step to do is determine the valence electrons of the two elements by using electron configurations.</p> <p>Electron configurations of iron and oxygen. Iron or Fe with atomic number 26 and oxygen with atomic number 8</p>  <p>(Looking back at the answer written)</p> <p>Oxygen with electron shell configuration 2 6 requires 2 electrons to achieve stability. If these 2 elements bind, then Fe will release 3 electrons so that</p> <p>Fe becomes Fe^{+3}, while O captures 2 electrons to O^{-2}. The load contained in each element is not the same number so it needs to be equalized.</p> <p>So the results obtained are</p> <p>Fe_2O_3.</p>	<p>(1) To determine the molecular shape of CO_2 we first look for the valence electrons of each binding element and determine the atom used as its central atom. Valence electrons can be obtained from the electron configurations of each element:</p> <p>Carbon, the valence electron 4 while oxygen has a valence electron 6, which means that C is able to bind to 4 other atoms</p>  <p>and valence electron from oxygen is 6 so that oxygen requires 2 electrons to achieve stability.</p>  <p>Now for CO_2 gas that is used as a central atom namely, C, or carbon with 4 valence electrons binding to O which has 6 valence electrons. The bonds between the CO_2 has 2 pairs of bonding electrons or 2 domains.</p> <p>Before we determine the molecular shape of a compound we need to pay attention to its free electron pairs, bonding electron pairs and its electron pairs, so we can determine the molecular shape of a compound.</p>  <p>Now here 2 PEI (with body movements), by making Lewis structure from the CO_2 we can</p>

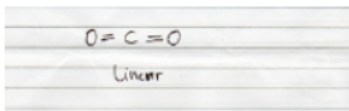
Respondent Code	Even semester	Odd semester
		determine the shape of the molecule. In my opinion the molecular shape of the CO ₂ is linear. because the central atom does not have all the free electron pairs, all electron pairs have been used to bind to oxygen so that the resulting molecular form is linear.
		

Table 6. Results of Thinking-aloud R2KMS of Even Semester and Odd Semester when Evaluating Results.

Respondent Code	Even semester	Odd semester
R2KMS	Yes, I'm sure my answer is correct because oxygen requires (writes) 2 electrons and Fe releases 3 electrons so that Fe ₂ O ₃ can form compounds that have stable valence electrons or the result of these two elements is equal to zero.	The shape of the molecule produced is linear because there is no repulsion between the free electron pair and the bonding electron pair so, I am sure, sure that the molecular shape of CO ₂ is linear.

4. Conclusion

Chemistry education students who are considered to have high metacognitive skills when solving a problem carry out three activities of thinking, namely planning, monitoring, and evaluation, and also consistently created external representation in both separate semesters. Thinking activities in problem-solving planning in the odd semester were more meticulous than the previous semester (even). In fact, even in this thinking activity, the students had been monitoring the planning process to reduce their mistakes. In addition, the knowledge possessed by students in this category had been growing over time as demonstrated by their ability to relate new information to the knowledge they have, to link between concepts, and supported by their ability to represent that knowledge externally. The same applies to their ability to evaluate results, the student was used to

regulating their own thinking in solving problems so as to increase her awareness to convince herself in decision making.

Chemistry Education student who were categorized as having intermediate metacognitive skills when problem-solving only conducted thinking activities in planning and monitoring consistently, but not in evaluating activities. His/her knowledge and ability to construct external representations also developed, but did not sufficiently to guarantee her success in problem-solving. That is why student in this category has a great chance of failing in solving a problem.

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