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CONDITIONAL KNOWLEDGE IN STOICHIOMETRY'S PROBLEM SOLVING

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ABSTRACT:
Conditional knowledge highlights the ways of solving the problem in a real-life setting. Everyday life applies open-ended questions and students need to link conceptual, procedural, and conditional knowledge to solve the problem. Thus, this qualitative research approach assesses the conditional knowledge of stoichiometry's problem-solving among high school students in Sabah. A total of 172 students from five different schools selected as respondents. The data obtained from one part of an open-ended test named 'Stoichiometry's Achievement Level Test' or UTPSK. There are three categories of implementing conditional knowledge among the students, which are good conditional knowledge, moderate conditional knowledge, and low conditional knowledge. The result shown majority students fall into low implementing of conditional knowledge. Furthermore, students' alternative framework appeared on each of the questions. It hopes that the findings of this research will provide useful insight into learning for the students and it contributes to the value of conditional knowledge to improve the ability of the students to solve problems in chemistry.

INTRODUCTION

Problem-solving is a complex cognitive process that requires precise multiple steps (Sansom, Suh, & Plummer, 2019). It involves the cognitive ability of higher-order thinking (Gayon, 2007) and the skills that demonstrate mastery of theoretical knowledge and professional practice across; content, knowledge, skills, and insights (Amolloh, Lilian, & Wanjiru, 2018). Besides, to be a successful problem-solver in science, students need to understand the conceptual, procedural, and conditional knowledge (Sansom et al., 2019).

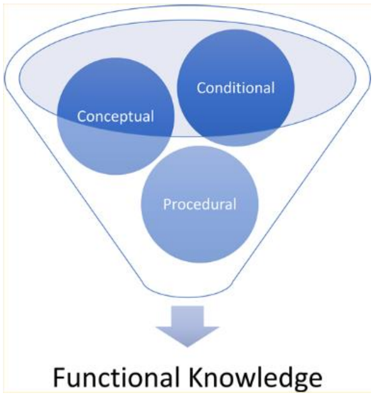

Figure 1. Functional knowledge in problem-solving (Sansom et al., 2019)

Conceptual knowledge referred to interconnections between the essential elements in a more massive structure that allows them to work together within a discipline (Krathwohl, 2002). Procedural knowledge describes how things are done, including step-by-step techniques, methods, algorithms, equations, and methods for problem-solving (Sansom et al., 2019). The conditional knowledge is a combination of two forms of knowledge that are conceptual knowledge and procedural knowledge (Mthethwa-kunene, Onwu, & Villiers, 2015). Importantly, conditional knowledge benefited the student to make them realize the most appropriate strategy for each type of problem as crucial concepts are learned (Sansom et al., 2019). Thus, besides conceptual and procedural knowledge, conditional knowledge plays a significant role in being successful in problem-solving.

Many chemical educators reported that students had difficulties when they solved the problem that involves stoichiometry's concept (Omwirhiren & D, 2015); (Danjuma, 2011); (Chandrasegaran, Treagust, Waldrip, & Chandrasegaran, 2009); and (Agung & Schwartz, 2007). Most chemistry students' lack of problem-solving skills and cause restricts their progress. It is due to students learning. They tend to memorize newly facts that do not relate to acquired materials in ways that make sense to the learner (Novak, 2008). In reality, learning in science not only brings a new concept to knowledge but often involves reorganization in thinking and building new ideas that may conflict with previous beliefs (Mondal & Chakraborty, 2013). Hence, this research tends to study the achievement of a student on their conditional knowledge of stoichiometry's problem-solving.

The research's primary goal is to access the implementation of conditional knowledge of students when doing their stoichiometry's problem-solving.

LITERATURE REVIEW

Determinants for Conditional Knowledge

Previous research discovered that there are two factors in one's knowledge base that affect the effectiveness of solving the problem which is (1) domain-specific knowledge or field of study; and (2) domain-general knowledge that used across the domains (Chase & Simon, 1973)(Halmo et al., 2018). Experts and novice student posse a different thought of knowledge base and its depend on their schemas (Halmo et al., 2018). Schemas are structure in human memory that allows similar experiences to be processed, synthesized, replicated, and retrieved (Marshall, 1995). For experts, they posse a well-organized particular domain of knowledge base with constructing mental schemas that bind related ideas into handy chunks while, in contrast, novice hardly trying to solve the problem because relevant schemas still need to be created (Halmo et al., 2018). Hence, domain-specific knowledge and domain-general knowledge are essential to building the well-organized schemas that helping students on their problem-solving skills.

This paper focuses on the ability of students when they are doing stoichiometry's problem-solving in conditional knowledge. To understand and solve a problem, students need to (1) distinguish relevant question features, (2) merge domain-specific concepts with features, (3) select the appropriate of an equation or procedure for the concept, and (4) conduct the procedure to solve the equation. The first three steps comprise the conditional knowledge itself (Sansom et al., 2019). However, this section only discussed (2) and (3) components and also conditional knowledge focused on chemistry problem-solving.

Concept Association

For chemistry, conceptual knowledge falls into three, which are macroscopic level, microscopic level, and symbolic level (Johnstone, 1993). Each level plays the specifics rules on chemistry knowledge. For the macroscopic level, it referred to a real phenomenon that can be seen in the laboratory as well as in our everyday lives (Treagust & Chittleborough, 2001). Specifically, the macroscopic level used to describe the concepts and ideas of chemistry itself (Johnstone, 2000). The microscopic level involves knowledge that cannot be touched (Barak & Hussein-Farraj, 2013) and only accessible through the visualization (Bucat & Mocerino, 2009). It is used to explain the behavior or the way the chemical substances do (Taber, 2013). For symbolic level, formulae, and the changes of an equation used to represent the chemical substances (Taber, 2013). Thus, these 'multiple thought' makes students face difficulties in learning chemistry (Johnstone, 1991).

Much research has shown the connectivity of three levels of chemistry with achievement student's levels of chemistry. Students with a high conceptual understanding of chemistry demonstrated a strong impact in reaching their goals of problem-solving (Gultepe, Celik, & Kilic, 2013). Moreover, students easily faced alternative frameworks when they have weak achievement in their conceptual knowledge (Salina, Johari, & NorHasniza, 2019). Hence, in chemistry, the connections between the domain of conceptual knowledge play essential roles in student success in problem-solving (Becker, Stanford, Towns, & Cole, 2015).

Procedure Selection

In reality, many students face difficulties with fundamental concepts that ask in problem-solving of stoichiometry. Most of them used algorithms techniques when solving the problem without understanding the hidden scientific concept behind (Robinson, 2003)(Salta & Tzougraki, 2011). To be worst, they tend to memorize varieties of algorithm techniques rather than using the conceptual knowledge to get the 'correct solution' (Robinson, 2003) (Mensah & Morabe, 2018). Moreover, it defected the students' procedural knowledge performance, with many errors that appeared (Mensah & Morabe, 2018).

Procedural knowledge is understanding how to do things, from simple sequences of action to complex actions, and to be a successful automatic performer; we do need practices (Schraw, 2006). (Schraw, 2006) added three sequences of action in procedural knowledge, which are complex scripted actions, algorithms, and heuristics. Scripts referred to extended courses of action and plans that stored as a single information unit of memory. It helps someone to remember the complicated step of activities from the organized of procedural knowledge. The heuristic used to solve the ill-defined problem with no definite number of solutions. (Schraw, 2006) define it as a thumb rule for solving a problem that often works, but not always. The algorithm is a rule used to solve the problem. It consists of a smaller step inside and suggested as an effective way to solve well-defined problems (Pretz, Naples, & Sternberg, 2003) and also useful act as an exercise (Frank, Baker, & Herron, 1987). However, in problem-solving chemistry, is a robust conceptual understanding rather than memorizing learning (algorithms) (Johari, Nor Hasniza, & Siti Fairuz, 2014).

Conditional Knowledge

Conditional knowledge requires concepts, principles, laws, scientific theories, postulates, and theories (Angela & Antonietti, 2012), and this connected directly to the need for conceptual and procedural knowledge when solving the problem (Mthethwa-kunene et al., 2015). (McCormick, 1997) defined conditional knowledge in specific action as "the how-to-decide-what-to-do-and-when-to-do-it knowledge." Moreover, expert chemists used conditional knowledge to determine when and under what circumstances they should use as a particular problem-solving method (Sansom et al., 2019) (Schraw, 2006). It helps students to organize the problem-solving process in the working steps to solve the problem (De Jong & Ferguson-Hessler, 1996). Thus, the importance of conditional knowledge attracting more researchers such as (Sansom et al., 2019), (Markovits, Brisson, & de Chantal, 2016) and (Aljaberi, 2015) to study the impact of conditional knowledge in problem-solving.

Conditional knowledge problem solving emphasizes the ways of questioning in a real-life setting. In reality, everyday life often applies open-ended questions, and this has a positive impact on students ' development of problem-solving skills (Reid & Yang, 2002). In essence, the types of questioning that apply in real life are realistic as they link theory with learning and can continue to use in daily life. Generally, conditional knowledge developed over time and experience. Hence, with limited time of learning and insufficient experience, novice chemistry students will face difficulties in developing conditional knowledge without explicit instruction (Sansom et al., 2019).

Stoichiometry's Problem Solving

Stoichiometry is one of the core principles and challenging topics for chemistry students because it is conceptually complex and requires a variety of quantitative approaches to problem-solving. Studies in science education reveal that it is difficult for high school students to understand and solve the stoichiometry problem (BouJaoude, And, & Barakat, 2003) (Dahsah & Coll, 2008) (Niaz & Montes, 2012). There are four types of problem-solving in stoichiometry, and the classification based on the information given and information needed to find (unknown). (Davis, Frey, Mickey, & Jerry, 2009). It involves (i) given and unknown quantities are an amount in moles; (ii) given is in moles, and unknown is a mass expressed in grams; (iii) given is in grams and unknown is an amount in moles; (iv) given is in grams and unknown is in grams. Each, have its specified procedure knowledge that combines several conceptual knowledge in stoichiometry's concept (Davis et al., 2009). The extended complexity of this topic continues with finding the limiting reactant in a reaction (Davis et al., 2009). Thus, stoichiometry is demanding topics because it incorporates the conceptually complex and demands a variety of methods towards quantitative problem-solving.

RESEARCH METHODOLOGY

Method and Data

The purposeful sampling was used to assess the population of high school in the state of Sabah. The samples were select from Sabah's best school based on their ranking place in SPM 2018 (top 10's). Furthermore, the students also took chemistry as their choice as their elective subject. As a result, 172 students from five schools of form four in three different districts identified as respondents. A detailed analysis was used to assess how students reacted and applied while answering the conditional knowledge of stoichiometry's problem-solving. Thus, a qualitative approach was used to determine the achievement level and also an alternative framework that appeared when conducting the problem-solving of stoichiometry. Thematic analysis is used to categorize the student while answering the questions.

The Achievement Level Test or UTPSK created by the researcher, and it consists of two open-ended questions. For both items, a total of ten marks provided. Two senior lecturers (Ph.D.) and two Master lecturers who are experts and have more than ten years of experience in chemistry education have gained to do the face validity and content validity. It is to ensure that the test had achieved the level of research needs. Initially, the problem tests the student in the way of how they manage and solve the problem by using the required minimum of information. Student needs to apply the conceptual knowledge they learned with a good route of procedural knowledge to solve problem-solving. The daily life questions were also created in conjunction to form a good conditional knowledge of the problem. Thus, students need critically to think in-depth to manage the solution to the problem.

Students need to complete their process of solving the problem through several phases regarding the use of their conceptual knowledge and procedural knowledge. For conceptual knowledge, it involves the understanding of various concepts such as particulate nature of matter, conservation of matter, mole, Avogadro's number, limiting reagent, the conversion formula, balancing chemical equations, laws of definite and multiple proportions (Niaz & Montes, 2012). Afterward, the procedural knowledge of how students used measured relating to their procedural skills. Engaging both of this knowledge will help them to fulfill the needs of conditional knowledge. For research, the marks based on the students' correct work actions. Thus, the detailed analysis of the student's answered done based on the marking scheme — finally, the student's level calculated from the data analysis. Percentages used based on the number of students that represented each of the categories. Here is an example of one of the problems.

<u>Question 1</u>

Uncle Chua is a modern farmer who cultivates vegetables on a farm located in Kundasang, Sabah. He is aware that fertilizer is a necessity for his farm because its high nitrogen content increases the growth of vegetables. Hence, Uncle Chua is considering to buy the best fertilizer but not sure which one to choose from the following list:

Ammonium sulphate, $(NH_4)_2SO_4$	Urea, NH_2CONH_2	Hydrazine, N_2H_4

As someone who knows chemistry, how can you help Uncle Chua? Show relevant evidence.

[Relative atomic mass: H, 1; C, 12; N, 14; O, 16; S, 32]

Question 1 is an example that happens in our real-life situation, and as a student, they have to read, plan, and consider such the use of conceptual knowledge and procedural knowledge to solve the question. Besides, they must choose one of the fertilizers that fitted with Uncle Chua needed.

RESULT & DISCUSSION

Content analysis studies has been used to assess students' conditional knowledge while doing their stoichiometry's problem-solving. Each of the students' answers analyzed and categories in detail based on their performance. Mason & Crawley (1994) classified problem solving into categories followed by students' performance. Thus, a high level, a moderate level, and a weak level are used to differentiate students' performance, and these extracted from the students' answered. Table 1 indicates the categories and levels of students.

Table 1. Categories and Levels of Conditional Knowledge of Students' Problem Solving

Categories of Student's Answer	Level
Implementing the good conditional knowledge	*High*
Implementing moderate conditional knowledge	*Medium*
Implementing the low conditional knowledge	*Low*

From Table 1, there are three categories of students answered base on their implementation of conditional knowledge. Conditional knowledge measured based on when and under what circumstances they should use conceptual and procedural knowledge as a particular problem-solving method in a real-life setting. For good conditional knowledge, a student shows the correct scientific concept in sequences and logically can adapt in a real-life situation — same goes to moderate and low conditional knowledge but different based on their level. Thus, the way of student thought critically analyze to explore the ability of student when solving the stoichiometry's problem focusing on conditional knowledge. The percentage values for each category are used to represent the number of students. Table 2 shows the finding of the study.

Table 2. Analysis of Students Implementation of Conditional Knowledge in Stoichiometry's Problem-solving

Implementation of Conditional Knowledge	Students No.		Average	Percentage
	Question 1	Question 2		
Good	21	17	19	11.05
Moderate	82	4	43	25.00
Low	69	151	110	63.95

Based on Table 2, the finding showed that only 11.05% or 19 students classified as high levels of implementing conditional knowledge in stoichiometry's problem-solving. In this case, students had an excellent understanding of conditional knowledge with no alternative framework. 25.00% or 43 students get a medium level of conditional knowledge with a moderate number of alternative frameworks. In contrast with the high level of conditional knowledge, 63.95% or 110 students were low levels in conditional knowledge with existences a lot of alternative frameworks. Thus, the majority of students fall into low in implementing conditional knowledge while doing their stoichiometry problem-solving.

In this study, we identified the implementation level of conditional knowledge and associated difficulties for the student while solving stoichiometry's problem. Thus, the detailed discussion of Question 1 will refer to this functional knowledge of problem-solving.

Conceptual Knowledge
Conceptual knowledge of chemistry based on three-level (triplet), which are macroscopic level, microscopic level, and symbolic level (Johnstone, 1993). Hence, students should build up their chemistry knowledge of transferring into a triplet level. Figure 2 shows how these triplets explaining the question needs.

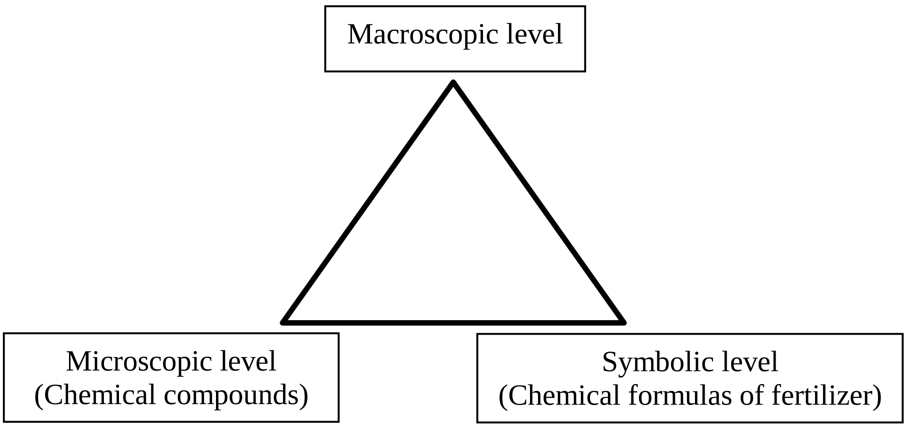

Figure 2. Explaining Question 1 by using a triplet level

As shown in Figure 2, we notice each fertilizer (macroscopic level) own their specific chemical formula (symbolic level) that comprises the elements in relative proportions (microscopic level). For question 1, the triplet level suited with the scientific concept of Relative Molecular Mass (RMM), and it could count from the chemical formula given for the fertilizer. The RMM also reacts as a domain-specific knowledge for stoichiometry's concept of students learning. However, comparing the RMM values is not a good judgment to choose the great fertilizer for Uncle Chua. It must parallel with the condition given by the farmer, Uncle Chua, which needs to select the highest values of nitrogen composition. With that, the student needs to merge the domain-general knowledge onto the RMM values. Both domains play essential roles in this problem and this parallel with (Chase & Simon, 1973) and (Halmo et al., 2018) as well. The student should find the percentage of the RMM for nitrogen compound per overall RMM values for fertilizer. Finally, the highest percentage values of nitrogen are the most exceptional choice for Uncle Chua.

From finding, there are minority students is at a high level of conceptual knowledge. They efficiently used the RMM concept and percentage when choosing the most top nitrogen compound of fertilizer. Nevertheless, one-fourth of students with a moderate level of conceptual knowledge and also faced with alternative frameworks while explaining the choice of fertilizer. Students cognitively understood to determine the RMM number of fertilizers. However, it too early to make use of the value as a fixed consideration while choosing the best fit of fertilizer. Besides, students created a variety of assumptions, such as high, moderate, or even low values of RMM, while finalizing the decision. Traditionally, students learn algorithmic methods to solve the problems, but they never develop an understanding of the scientific concepts behind them (Robinson, 2003). In the end, they lost the knowledge of the microscopic level (nitrogen compound) while explaining the best choice of macroscopic phenomena (best fertilizer) (Becker et al., 2015).

The majority of students fall into a low level of conceptual knowledge, and a lot of alternative frameworks appeared here. They did not merge the problem given with the RMM concept. Even, there are numbers of student did not know how to calculate the RMM for fertilizer. It happens when the problem incorporates the fundamental concepts of stoichiometry (Robinson, 2003), and students are struggling to use algorithmically to fit with a symbolic level of chemistry (Becker et al., 2015). To be worst, students did not grasp the connection between the answer and the fundamental level of chemistry is (Hadfield & Wieman, 2010). Hence, to develop a vigorous understanding of basic chemistry concepts in problem-solving, students must be able to connect their knowledge from the macroscopic level to the microscopic level and symbolic level (Salina et al., 2019).

Procedural Knowledge

According to the findings, the majority of students have difficulties while doing their procedural knowledge of problem-solving. Question 1 is an example of an ill-structured problem that needs an in-depth student's understanding of conceptual knowledge and procedural knowledge to solve. Despite domain-specific knowledge, it also requires the use of domain-general knowledge to answer Question 1 (Halmo et al., 2018). Figure 3 shows the detailed procedure of solving the problem for Question 1.

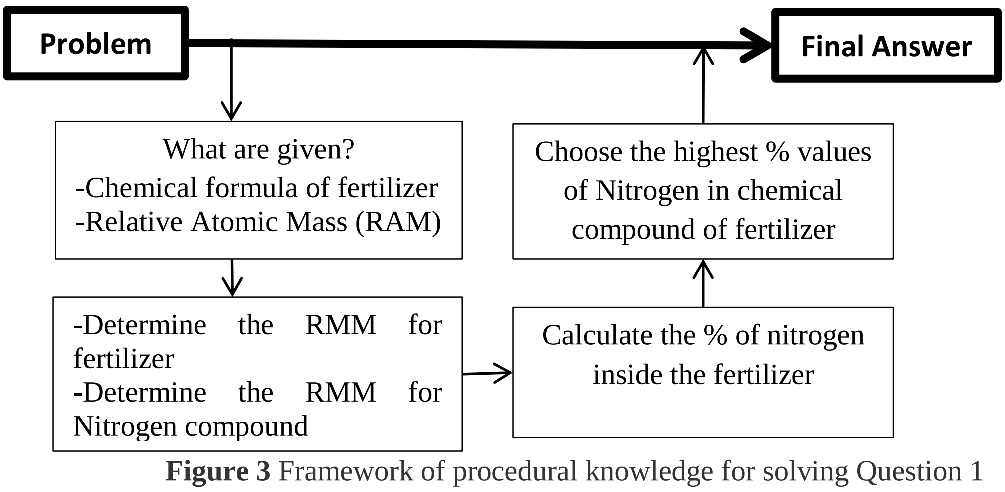

Figure 3 Framework of procedural knowledge for solving Question 1

There is a gap between the problem and the final answer. Students need to plan and propose procedural knowledge with the use of conceptual knowledge to fill in the gap. There are forth step in solving Question 1. Step 1 and 2 need the domain-specific knowledge about conceptual knowledge of RMM while step 3 and 4 was used of domain-general knowledge to solve the problem. For Step 1, the majority of students aware of what is given in the question. It is proof by the practical step that students used while answering the question. In step 2, although the majority of students successfully calculate the RMM value of fertilizer, only a few students can determine the RMM of the nitrogen compound. Students with low achieving applied algorithms solely at all processes of problem-solving with several errors (Mensah & Morabe, 2018). Hence, it affected the procedure of steps afterward.

In contrast, only a few students successfully followed in steps 3 to 4, until they made the best choice of fertilizer. (Mensah & Morabe, 2018) state in their study, a student with high-achieving shows conceptual understanding while solving the common problem, but they made a few errors when dealing with the unfamiliar context of the problem. Hence, procedural knowledge is not only memorized the varieties of algorithm techniques, but it must stand with a scientific conceptual understanding of chemistry to drive students into the 'correct answer' (Robinson, 2003; Mensah & Morabe, 2018).

Conditional Knowledge

From studies, only a minority of students categorize as good in implementing the conditional knowledge of solving the problem. Students with a high level of conditional knowledge would able to identify the best approach to address the specific learning situation (Schraw, 2006), and it directly depends on their schemes (Marshall, 1995). Well-organized schemes play prominent roles in assisting students while solving the problem. It created from domain-specific knowledge and domain-general knowledge of student's learning in the context of school and also a real-life experience (Halmo et al., 2018). Domain-specific knowledge is about the conceptual and procedural knowledge in chemistry. From research, the majority of students categorized as low in their conditional knowledge of stoichiometry's problem-solving. The student is weak in their domain-specific knowledge. In Question 1, there are numbers of a student who failed while connecting the given real-life problem with conceptual knowledge of stoichiometry. They did not have any idea what is a scientific concept should use. It shows that students only memorize algorithms techniques but not know what hidden scientific theory behind is (Robinson, 2003; Salta & Tzougraki, 2011).

In contrast, domain-general knowledge is an interaction of domain-specific knowledge with other domains of knowledge (Halmo et al., 2018). The application of general domains such as physics, mathematics, and statistics into solving promotes better problem-solving skills than solving problems alone (Halmo et al., 2018). There are one-quarter of students categorized as moderate in implementing conditional knowledge. At this stage, the student knows what domain-specific knowledge that needs to use but could not merge with domain-general knowledge. For example, in Question 1, students failed to use the mathematics concept to find the percentage values of the nitrogen compound. Thus, the implementation of conditional knowledge is depending on the formation of well-organized schemes of students.

CONCLUSION AND RECOMMENDATION

Conclusion

There are three types of associated functional knowledge in chemistry that importantly need to be a good problem solver, which are conceptual, procedural, and conditional knowledge (Sansom et al., 2019). Conditional knowledge comes from a real-life situation whereby conceptual knowledge and procedural knowledge of chemistry are needed to solve the problem. There are three categories of students emerged from a detailed analysis of students' answers while doing the conditional knowledge of stoichiometry's problem-solving. There are well implementing conditional knowledge, the moderate implementing of the conditional knowledge, and the low implementing of conditional problems. The minimal number of students categorized in well implementing conditional knowledge. In contrast, the majority of them categorized as the low implementing of conditional knowledge, and the rest number of students were moderate implementing of conditional knowledge. Besides, the alternative framework appeared on moderate and low implementing of conditional knowledge.

RECOMMENDATION

The limitation of this study is the methodology that we used. The data gathered only from selected high performances school at Sabah. Yet the data should take between novice and expert students. Besides, our investigating researched not generate quantitative data representing high school students. The result will deliberate a detailed description of problem-solving. Although qualitative data done by researchers, it only based on the content analysis from student's test, not in-depth qualitative research. So, it would be suggested to extend the research through a think-aloud and retrospective interview to get the real data of student difficulties while doing problem-solving of conditional knowledge in chemistry.

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