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Conceptual Knowledge in Stoichiometry's Problem Solving

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Abstract: ***This descriptive quantitative study aims to assess the level of student's problem-solving achievement in their conceptual knowledge of stoichiometry. A total of 71 students from two different schools in one district were chosen as respondents in this study. The data was obtained from a set of two-tier tests named 'Ujian Tahap Penguasaan Stoikiometri Kimia' or UTPSK. It consists of six questions purposed to measure the three components in chemistry knowledge, which are macroscopic level, microscopic level and also symbolic level. The result of the study showed that the students' achievement level for the macroscopic level was a moderate while for both microscopic and symbolic level was weak. The result also indicated that the students' misconception appeared at each level of their conceptual knowledge. It is hoped that the results from this research can provide meaningful input towards students' learning and contribute to the importance of conceptual knowledge to boost the ability of students problem-solving in chemistry.***

Keywords: ***Chemistry problem solving; Macroscopic level; Microscopic level; Symbolic level; Stoichiometry; Two-tier questions.***

I. INTRODUCTION

Problem-solving plays an importance role in our life. According to (Glover, Ronning et al. 1990), most of the times either like or not we were faced with the ill-defined, multifaceted and open-ended problem that need us to solve in our real-life situation. It's also involved more than one final solution and methods of problem-solving. To be a good problem solver, we need to be a critical and creative in thinking as well as the student. Students should be exposed to problem-solving skills regardless of the ages of their schooling.

Furthermore, students need to master the skills in problem-solving to ensure they can apply the knowledge in the context of their daily lives. Conceptual knowledge is one of the main components in problem-solving. It becomes an indicator to determine the students' performance (Friege and Lind 2006) because conceptual knowledge involves facts, theories and concepts of chemistry (Shavelson, Ruiz-Primo et al. 2005, Johari, Nor Hasniza et al. 2012). In addition, the chemistry knowledge is multi-dimensional and also complex (Thomas and McRobbie 2012). Thus, the conceptual

knowledge plays the essential roles in the achievement of problem-solving in chemistry among the students.

II. The Literature Review

A. Problem-solving in Chemistry

According to Broman and Parchmann (2014), the problem-solving question can help students to be a good problem solver. It's benefited for them in terms of explaining the chemical phenomena in a more structured and effective way. Problem-solving is the process of linking the context and also a situation, which depends entirely on the structure of in-depth knowledge and also experience of a person (Palumbo 1990). However, the relation to the context of knowledge is something critical in problem-solving (Beyer 1984) because it involves the combination of several principles such as technical details, generalization, heuristic algorithms and some information relevant to the problem (Stevens and Palacio-Cayetano 2003). Hence, it is not surprising when the findings by (Ouasri 2017); (Overton, Potter et al. 2013); (Cartrette and Bodner 2009); and also (Salta and Tzougraki 2010) shown that the students have difficulty in their problem-solving in chemistry from well-structured to ill-structured problem.

(Jonassen 2004) classified the problem into two types, which are well-structured and ill-structured. Figure 1 shows the difference between these two types of problems.

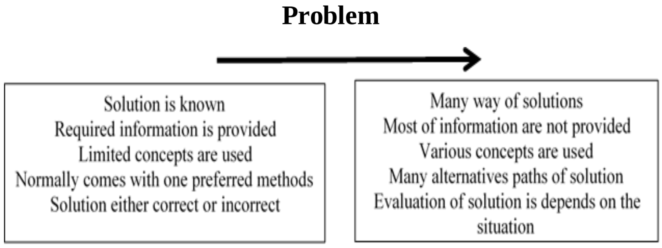

Fig 1. Differences between well-structured and ill structured problem

According to (Jonassen 2004), the well-structured problems are typically used in schools, universities and training centers because it involves limited concepts, rules, and principles. The form of the well-structured problem is also clear and more precise with the used of logical operation and certain procedures. In contrast, the ill-structured problem involves interdisciplinary studies, especially in everyday life, as

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well as professional practices. Student needs to formulate his hypothesis and test it through a series of tests and improvement until the problem are solved (Lesh and Harel 2003). Therefore, it's required the application of the concept and principles in various domains to enable it to resolve. Thus, that is, the students always face difficulties when the question leads to an ill-structured problem.

(Ouasri 2017) identified two issues of students' difficulties in doing problem-solving in chemistry. First, student lack of understanding of certain concepts in chemistry and this is included the semantic and linguistic skills of chemistry knowledge. Secondly, the student also lacks in their mental representation of three levels in chemical representation, which are macroscopic, microscopic and symbolic level. Both of the issues are directly connected with the conceptual knowledge, which is the basic need in doing problem-solving of chemistry.

B. Conceptual Knowledge

Conceptual knowledge is a static knowledge of facts, concepts and principles that can be used in a particular domain to enhance the information of problem solver (de Jong and Ferguson-Hessler 1996). This is in line with (Jonassen 2009) who stated that problem solver needs to understand each of the structure in their operation concept of knowledge as well as the integration with other concepts when doing problem-solving. If this happens, the adaptation and reestablishment process will occur, and this will reflect a view of the person and increase their experiences too (Jonassen 2009). The students' ability in doing problem-solving will also be increased as well as they can implementing, linking and formulating the existing concepts to a new concept (She 2004) and (Barak, Harward et al. 2007). This will lead to the addition of complex knowledge in terms of theoretical concepts and models.

Problem-solving played an important role to stimulate the development of conceptual knowledge to the students (Nersessian 2008) and (Chwee and Murcia 2013). The formation of conceptual knowledge different due to the subjects. In chemistry, it is based on the three levels of chemistry representation (Ried and Yang 2002); (Thadison 2011); (Talanquer 2010); (Taber 2013); and (Sim and Mohammad Yusof 2014). The three levels of chemistry representation are macroscopic level, microscopic level and symbolic level. According to (Nieves, Barreto et al. 2012) student shows the higher ability in problem solving skills when they're mastered in the scientific concepts of the three level of chemistry representation. The studies from (Sim and Mohammad Yusof 2014) and (Helsy, Maryamah et al. 2017) shown that students faced the various of misconceptions when they lack of conceptual knowledge in the three level of chemistry representation. It was also supported by (Johari, Nor Hasniza et al. 2012) who also found that when students' have misconceptions in three level of representation also affected their performance on problem solving in chemistry. Figure 2 shows the relationship between three levels of representation in chemistry.

Macroscopic level

Microscopic level Symbolic level

Fig 2. Three Level of Chemistry Representation Source: Johnstone (1991)

The macroscopic level is a real phenomenon that can be seen directly in the laboratory and also in our daily life (Treagust, Chittleborough et al. 2003). The macroscopic level also being used to describe something in the view of chemistry concepts and ideas (Johnstone 2000). In contrast, the microscopic level involves an unobservable knowledge that can't be touched (Barak and Hussein-Farraj 2013). It's only accessible through the visualization (Bucat and Mocerino 2009). For symbolic level, it is the representation of knowledge in the form of various media such as models, pictures, algebra, mathematical problem solving (Johnstone 1982, Johnstone 1993) using coefficients, subscripts, chemical charges and the use of algebraic representations (Thadison 2011). In other word, the symbolic level can represent the substance and chemical reaction in a way to describe macroscopic and microscopic level (Bradley 2014).

Majority of the students have difficulties in linking their experience or in a real-world situation to the conceptual knowledge of chemistry representation (Gabel 1999). Students had challenges in characterizing the concept of macroscopic levels, such as heat and weight (Driver, Squires et al. 1994). Most of the research such as (Nakhleh 1993) and (Garnett and Hacking 1995) also revealed that students encountered difficulties when approaching the problem that involved microscopic level and they did a lot of misconception on this area. They also could not link the one level to another level of chemistry representation (Sanger 2005). It means that student needs to master the three level of chemistry knowledge to increase their performance on doing an ill-structured problem (Ried and Yang 2002).

C. Stoichiometry's Problem Solving

Stoichiometries is a basic knowledge in chemistry that needs an in-depth understanding of chemistry phenomenon in terms of qualitative and quantitative methods to enable it to use when solves a wide range of chemical problem (Sunyono, Yuanita et al. 2015). However, students always get lower achievement in their problem-solving stoichiometry's conception. This is in line with the findings of (Piquette and Heikkinen 2005); Sanger (2005); (Haider and Naqabi 2008); (Chandrasegaran, Treagust et al. 2009); (Mansoor and Montes 2012); (Gulacar, Overton et al. 2013); Sunyono et al, (2015); (Hanson 2016); (Kamariah and Daniel 2017); and also (Mandina and Ochonogor 2017). This is due to several factors such as lack of skills in writing formulas (Facer 2008), lack of skills to balance the chemistry equation and predict the product of chemical reaction, do not understand the mol concept and limited reagent, and also the wrong used of interrelation formula in stoichiometry's (Mandina and Ochonogor 2017). Hence, this research tries to find the students constraints when they are doing stoichiometry's problem solving within Malaysian education cultural.

In brief, problem-solving skills play a big role to develop students conceptual's understanding of chemistry. As discussed earlier, students need to master these three levels and also their interrelation to become a successful problem solver in chemistry. Thus, the purpose of this research is to identify the students' achievement level of conceptual knowledge in stoichiometry's. In detail, the research was focus on the three levels of chemistry's conceptual knowledge, namely macroscopic level, microscopic level and symbolic level. The objectives of this research are:

- To identify students' achievement levels in solving the macroscopic level
- To identify students' achievement levels in solving the microscopic level
- To identify students' achievement levels in solving the symbolic level

III. METHODOLOGY/MATERIALS

A quantitative study using a descriptive analysis has been used in this research to fulfil the research objectives. Paper and pencil test were a tool of the data collection. The data was collected around October 2018 from two different schools in one of the districts in Malaysia. The questions were developed by the researcher. Face validity and content validity has been obtained both from two senior lecturers (PhD) and also two Master lecturers who are specialist and have more than ten years experiences on chemistry education. This is to ensure the test was able to measure the needs of the research. A set of tests UTPSK was consist of six multiple-choice questions (2 marks per correct question) have been given to 71 respondents Form Four (45 males and 26 females) who enrolled as a science stream student. The two-tier test was used to determine the students' achievement level and also to reveal their misconception of stoichiometry's concept.

To measure the conceptual knowledge on the three levels of chemistry, they also need to explain their choice in the second part of the question. Marks will be given based on the schemes with a maximum of five marks per question. Statistically descriptive methods were used to analyze the data. Thus, frequencies and percentages were used to get information about the data. The full score is 42, and the final marks will be given in percentages. The student's achievement level was categorized into three, which are high, moderate and low performances. A student who gets the scores equal or more than 70 are categorized as a high achiever. Students are classified as a moderate level if they got the scores between 40 to 69 marks. For low achievement, the scores are the same or less than 39 marks. Table 1 shows the scoring scheme which based on guideline provided by the Ministry of Education (MOE).

Table 1. Score level for Stoichiometry Problem Solving of Conceptual Knowledge

Score (percentage)	Level
70-100	High
40-69	Moderate
0-39	Weak

IV. RESULTS AND FINDINGS

This part focused on the finding of students' achievement levels in conceptual knowledge of stoichiometry's problem-solving. Marks was given based on the correct response of the students. Table 2 shows the overall level of the students' conceptual knowledge of problem-solving.

Table 2. Overall Level of Students' Conceptual Knowledge of Problem Solving

Levels of Concept	Concepts	Average Marks (%)	Overall Average (%)	Level of Achieve -ment
Macroscopic Level	Limiting reagent	16.11		
	Relative Molecular Mass	64.58		
Microscopic Level	Moles & number of particles	28.58	29.07	Weak
	Chemical equation	7.45		
Symbolic Level	Molecular formula	46.07		
	Constructing the ionic equation	11.64		

Based on Table 2, the overall marks was 29.07%, and it was categorized as a weak achievement. Its shows that the highest scores of the students only reached a moderate level of achievement. Some of the concepts also did not fulfil by the students such as limiting reagent, moles and molecular mass, chemical equation and also constructing ionic equation.

A. Students' Level of Conceptual Knowledge in terms of Macroscopic Level

Objective 1: To identify students' achievement level in conceptual knowledge of problem-solving at the macroscopic level

In the macroscopic level, two concepts used to test the students' conceptual knowledge of problem-solving. There are the concept of limiting reagent and also Relative Molecular Mass (RMM). Table 3 shows the student's achievement level on the macroscopic level.

Table 3. Students' Achievement for the Macroscopic Level

Levels of Concept	Concepts	Mark (%)	Averag e (%)	Level of Achieve-ment

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Macroscopic	Limiting reagent	16.11	40.35	Moderate
	RMM	64.58		

Based on Table 3, it can be seen that students' achievement on the macroscopic level of stoichiometry problem solving was moderate with the average marks 40.35%. The score only reached the minimum requirement for the moderate level. Although the student can score 64.58% on RMM but not in the concept of limiting reagent, which was only got 16.11%. For limiting reagent, this question was concerned in the neutralization process of acid and alkali. Student needs to give their explanation on the macroscopic level in the second part of the two-tiered question. Table 4 shows the analysis for question asking about the concept of limiting reagent.

Table 4. Detail Analysis for Question asking about Limiting Reagent at Macroscopic Level

Students responses	Frequency	%
Scientific concept		
S1 Sodium hydroxide solution is a limiting reagent in the reaction of neutralization process. When it reached the endpoint, all of the added acids were fully reacted with alkali to produce salt, and the solution turns colorless	21	49.30
S2 Phenolphthalein act as an indicator in the neutralization process	3	
S3 Titration is a process used in the neutralization reaction	11	
Misconception		
M1 Hydrochloride acid reacts and bleached the color of phenolphthalein solution	11	
M2 Phenolphthalein was diluted	3	
M3 Hydrochloride acid is limiting reagent	3	
M4 Sodium hydroxide was diluted	1	29.60
M5 Sodium hydroxide was filled per drops until it reaches the endpoint	1	
M6 The product was bleached the phenolphthalein solution	1	
M7 Sodium hydroxide neutralizes the phenolphthalein solution	1	
No response	15	21.10
Total	71	100.00

Based on Table 4, 49.30% students have to understand the concept of limiting reagent, 29.60% students have a problem due to the concept of limiting reagent and 21.10% did not give any responds to the question. This finding is also supported by (Hanson, 2016). Limiting reagent is a necessary step in determining amounts of product in chemical reactions (Hanson 2016). At the macroscopic level, the student can see the color change of the solution, but they failed to connect it with conceptual knowledge of limiting reagent. They also did not understand the function of acid-best indicator to detect the equivalence point of titrations.

B. Students' Level of Conceptual Knowledge in terms of Microscopic Level

Objective 2: To identify students' achievement level in conceptual knowledge of problem-solving at the microscopic level

For the microscopic level, there are two concepts that test the students' conceptual knowledge in stoichiometry's problem-solving. There are moles and number of particles and also the concept of a chemical equation. Table 5 shows the student's achievement level on the microscopic level.

Table 5. Students' Achievement for the Microscopic Level

Levels of Concept	Concepts	Marks (%)	Average (%)	Level of Achieve-ment
Microsco-pic	Moles & number of particles	28.58	18.02	Weak
	Chemical equation	7.45		

Table 5 shows that the achievement level for stoichiometry's problem-solving at the microscopic level was weak with 18.02%. It is proof that the students have low competency both of the concepts. The various misconceptions also found in the analysis both of the questions. Table 6 exhibit the data analysis for the question asking the concept of moles and number of particles at the microscopic level.

Table 6. Detail Analysis for Question asking about Moles & Number of Particles at Microscopic Level

Students responses	Frequency	%
Scientific concept S1 Iron (II) chloride, $FeCl_2$ is ionic substances Given, number of moles for $FeCl_2$ = 0.3 moles So, the number of formula unit ($FeCl_2$) is = 0.3 x 6.02 x 1023 = 1.806×10^{23} units Based on the formula, $FeCl_2$ consist of 3 ions That are 1 ion of Fe^{2+} and 2 ions of Cl^- Therefore, the total numbers of ions formula are = 3 x the number of ion formula $FeCl_2$ = $3 \times 1.806 \times 10^{23}$ = 5.418 x 1023 ions	12	16.90

Misconception		
E1 Do not multiple the total number of ions in $FeCl_2$	38	53.52
E2 Molecules number of $FeCl_2$ was written as 2 in calculating the number of formula units	2	2.82
E3 Ions number is the same as N_A (6.02×10^{23})	2	2.82
E4 Used the wrong formula when calculating the number of ions	2	2.82
No response	15	21.10
Total	71	100

As shown in Table 6, 16.90% of students were given the correct responses, 61.98% of students have misconceptions, and 21.20% did not answer the question. From the misconceptions, 53.52% of students did not know to multiple the number of ions in $FeCl_2$. 2.82% each were written two as the number of ions in $FeCl_2$; written ions number same as Avogadro's Number and used the incorrect formula when calculating the number of ions. It's would not easy to answer the question when students did not understand the concept of ions formula. Furthermore, the majority of them thought the number of particles was the same either in molecules or in ions. These findings also supported by (Case and Fraser 1999). They stated that students have difficulties on the microscopic level when doing stoichiometry calculations. According to (Hafsah, Rosnani et al. 2014), the ability of students in doing the stoichiometry problem solving was depended on their understanding of the mole concept and the problem representation. Thus, students need to understand in dept at the microscopic level in order to increase their ability in solving chemistry's problem-.

C. Students' Level of Conceptual Knowledge in terms of Symbolic Level

Objective 3: To identify students' achievement level in conceptual knowledge of problem-solving at the symbolic level

For symbolic level, there are also have two concepts that test the students' conceptual knowledge of stoichiometry's problem solving. There are the concept of molecular formula and also constructing the ionic equation. Table 7 shows the student's achievement level on the symbolic level.

Table 7. Students' Achievement for the Symbolic Level

Levels of Concept	Concepts	Marks (%)	Average (%)	Level of Achieve-ment
Symbolic Level	Molecular formula	46.07	28.86	Weak
	Constructing the ionic equation	11.64		

Based on Table 7, it shows that the achievement level for stoichiometry's problem-solving at a symbolic level was weak with 28.86 %, which is a bit higher than the result of the microscopic level. Thus, the result portrays the low competency of students both of the concepts above. The various misconceptions also found in the data analysis both of the questions. Table 8 present the data analysis for the questing asking the concept of the molecular formula.

Table 8. Detail Analysis for Question asking about Constructing the Ionic Equation

Students responses	Frequency	%
Scientific concept $Zn\ (p) + HCl\ (ak) \longrightarrow ZnCl_2\ (ak) + H_2(g)$ Balance the equation $Zn\ (p) + 2HCl\ (ak) \longrightarrow ZnCl_2\ (ak) + H_2\ (g)$ Split dissolved ionic subtances into separate ions $Zn(p) + 2H+(ak) + 2Cl-(ak) \longrightarrow Zn^{2+}(ak) + 2Cl^-\ (ak) + H_2(g)$ Cancel the spectator ions, which are the $2Cl^-$ ions in each side, $Zn(p) + 2H^+(ak) +$ ~~2Cl-(ak)~~ $\longrightarrow Zn^{2+}(ak) +$ ~~2Cl- (ak)~~ $+ H_2(g)$ $Zn(p) + 2H^+(ak) \longrightarrow Zn^{2+}(ak) + H_2(g)$ The reaction of acids involves H^+ ions Therefore, the reaction is between zinc atoms and hydrogen ions. Salt are ionic compounds containing metal ions	2	2.82
Misconception		
E1 The answer was given is in the form of balance equation not in the form of the ionic equation: $Zn\ (p) + 2HCl\ (ak) \longrightarrow ZnCl_2\ (ak) + H_2\ (g)$	46	64.79
E2 The answer was given in the form of unbalance equation: $Zn\ (p) + HCl\ (ak) \longrightarrow ZnCl_2\ (ak) + H_2\ (g)$	3	4.22
E3 H_2 gas was written in the form of H^+. H_2 gas has not dissolved the salt.	2	2.82
No response	18	25.35
Total	71	100

As shown, 2.82% of students only can answer the question. Majority of students (64.79%) did not understand the concept of constructing the ionic equation. Studied by (Kamariah and Daniel 2017) also shown the students also have difficulties in writing a balanced equation. According to (de Jong and Taber 2007), students had a problem to link the concept of balanced equation (algebraic concept) to the conceptual knowledge of chemistry. Practically, the steps for both of the constructing equation almost the same except for the process of separating ions. However, it was a critical step because they need to recognize the ionic substance either it can dissolve in water or not. Also, 25.35% of students were not given any responses on this question, 4.22% did not have the skills to balance an equation, and 2.82% did not recognize H_2 as an

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undissolved salt. Studied from (Hafsah, Rosnani et al. 2014) also stated that the students have a lack of skills involving writing chemical formulas, writing chemistry equation and even mathematics skills. Therefore, to increase the ability skills on constructing the ionic equation (symbolic level), students’ need to understand the scientific concept of the substance itself, which is directly connected with macroscopic level and microscopic level.

V. CONCLUSION

A two-tiered question has been used to identify the student's achievement level in their conceptual knowledge of stoichiometry’s problem-solving. The conceptual knowledge depends on student understandings on the three levels of chemistry, which are macroscopic level, microscopic level and symbolic level. For overall, students’ problem solving based on conceptual knowledge was weak. Specifically, students’ achievement for macroscopic level is moderate, and both for the microscopic and also symbolic level were weak. This is due to the existence of misconceptions in their conceptual knowledge of stoichiometry. Hence, teachers should be more emphasis on the use of chemistry representation levels while describing and explaining the conceptual knowledge in their instructions. The teachers should be aware that the student only holds the correct scientific concept about stoichiometries. One of the suggested is used of two-tiered question whereby students need to explain more in terms of their conceptual of knowledge in chemistry.

There are also have limitations in this study. It was a small investigation that only 71 respondents are involved. Furthermore, the instrument only consisted of six questions. Each of two items, test the macroscopic level, microscopic level and symbolic level of conceptual knowledge in stoichiometries. In order to validate the findings, the number of questions has to be extended as well as the number of respondents. Besides that, for the purposed of the extended data, the qualitative research should be done to understand in-dept of how the schemata of the students thinking when they are doing the problem-solving in chemistry focusing on their conceptual knowledge. It can help students to think more scientifically when doing problem-solving on chemistry

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