ISSUES IN TEACHING MOLE CONCEPTS FOR MEANINGFUL LEARNING

Adlin Premla Vincent Ramesh
Rose Amnah Abd Rauf
Hidayah Mohd Fadzil
Department of Mathematics and Science Education
Faculty of Education, Universiti Malaya

Abstract

The meaningful learning of Mole Concepts in chemistry has become a challenge to teachers worldwide. The implementation of the twenty first century learning to enhance thinking skills among students is currently emphasised in Malaysian government secondary schools. The continuous efforts of researchers worldwide over the decades have identified the obstacles to meaningful learning, which is the abstractness of chemistry subject. Hence, teachers opt for algorithmic teaching strategies that result in superficial understanding and use of memorised set of steps in problem solving. Researchers have contributed various teaching strategies to encounter this problem by promoting the need for an abstract concept to embark on prior knowledge as well as to engage students in the learning process actively. Another view on teaching method is by having a balance between the "know what" and the "know how" of an abstract concept which gives importance to the conceptual understanding as well as the systematic set of steps to solve problems to promote meaningful learning.

***Keywords**: chemistry concepts, abstract concepts, conceptual understanding*

INTRODUCTION

Chemistry education has become more challenging over the past few decades in the perspective of meaningful learning and higher order thinking skills globally. This challenge has ignited the researchers worldwide to focus on thinking skills and meaningful learning in order to find suitable ways to teach abstract topics such as mole concept in chemistry. Teachers often encounter problems teaching abstract topics such as mole concept in the view of meaningful learning. This is because teachers prefer to teach mole concept using the algorithmic teaching strategies which emphasises the steps of problem solving in contrast to the meaning of the concept itself. Currently, the implementation of the Standard Curriculum for Secondary School (Kurikulum Standard Sekolah Menengah, KSSM) in Malaysia, requires chemistry teachers to equip oneself with the twenty first century teaching methods that are more student-centered to promote meaningful learning. The revamp of the curriculum to KSSM is one of the efforts of the Malaysian Ministry of Education in line with the Malaysian Education Development Plan 2013-2025 (*Pelan Pembangunan Pendidikan Malaysia 2013-2025, PPPM*) (Ministry of Education, 2013). The implementation of KSSM began in the year 2017 for the form one level progressively in Malaysian government secondary schools, until it is completely in operation in the year 2021 for the form five level (Ministry of Education, 2013). This new curriculum is introduced to enhance students' thinking skills and reasoning in classrooms promoting student-centered and twenty first century learning skills in contrast to traditional teacher-centered teaching methods.

Challenges to meaningful learning in chemistry

The continuous efforts of researchers over the decades have identified some of the root causes that are the stumbling blocks to meaningful learning in chemistry. One of the problems identified is the ongoing problems of lack of conceptual understanding among students, due to the abstract nature of chemistry subject (Cardellini, 2012; Akcay, 2016; Shadreck and Enunuwe, 2017). Chemistry is regarded as an abstract subject because it has its own language of formulas, symbols, and representation for the unseen particles (Haidera, 2014; Gafoor and Shilna, 2015; Mairing, 2017). Students consider chemistry as a difficult subject because of its abstractness (Cardellini, 2012; Kimberlin & Yezierski, 2016; Sopandi, Kadarohman, Rosbiono, Latip, and Sukardi, 2018). One of the crucial topics in chemistry that needs attention is "mole concept" which is abstract involving chemical symbols, microscopic and mathematical in nature. This topic is one of the most important parts of chemistry and is taught at the beginning part of the syllabus. In the Malaysian chemistry syllabus, this topic is taught in the third chapter, in the first three months of students' fourth form, when they first encounter the new subject "chemistry". This topic requires one to be able to solve numerical problems involving mass, volume of gas and the number of particles which are unseen. Hence, there is a decline in interest among chemistry students when exposed to the complexity of this topic straight away at the beginning (Cardellini, 2012; Sheau, 2016; Akcay, 2016)

Teaching strategies of abstract concept

Various views and suggestions of teaching strategies have been proposed through research on this topic. One of the views of a researcher is that mole concept is lacking a contextual approach (Cardellini, 2012). According to the researcher, this has caused the failure of students to relate this topic to their daily life. It increases the perception of this topic as something difficult and can be learnt only in the classroom using the few steps taught by their teachers. When a topic is learnt in a contextual approach, it is being related to their daily life which acts as a foundation of prior knowledge to build up the newly learnt concept (Lee et al., 2001; Cobern, 2012). This view stresses the need for a student to relate the new information to something that they already know in order to reduce the abstractness of the topic. This is in line with the constructivists' views that students do not have an empty mind but have pre-existing knowledge as the foundation to build up new knowledge (Cobern, 2012; Milenkovic et. al., 2013). In reality, mole concept is a topic that is related to other fields and can be made into contextual approach through planning of suitable teaching approach (Cardellini, 2012; Milenkovic et. al., 2013).

Another important view on this strategy is the use of analogies in imparting an abstract concept. Akcay (2016) expressed the views that the use of analogies enables students to compare a known fact to the new topic learnt. Analogy is a method where the abstract concept is compared with a similar concrete example of an object or phenomena, that is well understood or familiar to learners (Pienta, Cooper & Greenbowe, 2005). The ability of students to compare the new information to a known fact can reduce their learning difficulties. The use of analogies is also a way of relating to one's prior knowledge in order to boost the understanding level of students on the abstract concept. Thus, an analogy enables students to get a clear picture of an abstract topic which can also be made contextual (Richland & Simms, 2015). For example, the concept of dozen can also be used as an analogy to the Avogadro's constant whereby both represent a quantifier that represents a certain number of objects. However, analogies depend on the thinking ability of a student and may cause confusion for those who are unable to relate the analogy (Pienta, Cooper & Greenbowe, 2005).

The use of contextual approach and analogies fall back to the Piagetian theory of formation of schema in the mind of a student. According to Piaget, every child has a countless number of schemata formed as a result of daily life experiences. Formation of a new schema on an abstract concept can be related to one of the pre-existing schemata. However, this responsibility lies in the hands of teachers to find an appropriate method to start with a strong foundation of prior knowledge.

Past researchers have tried various methods to present this topic to reduce its abstractness other than contextual approach and analogical methods. Another method used was to engage students in the lesson using interesting and engaging teaching aids. The LEGO method was used in a research by Molnar and Hamvas (2011), to help students solve the stoichiometric problems of mole concept. The usage of colourful building blocks was an effort to help learners visually solve the numerical problems. Although the researcher tried to engage students using colourful teaching aids that gained students attention, this method had a set of rules by itself in order to make it work to simplify the lesson on solving stoichiometric numerical problems. Gafoor and Shilna (2015), studied on the usage of cartoons to learn difficult concepts. In the cartoon strategy, ideas regarding scientific phenomenon are presented in the form of cartoon-style drawing in a discussion format. Then, the students are invited by their teacher to debate with the cartoon characters. This method promotes students' involvement in the learning experience and generating their ideas on the concept. Furthermore, it gains students attention on the topic, but it does not consider the students of lower cognitive ability who are passive. The extroverts who are verbally eloquent may benefit from such an interesting debate session but not all. This method presents new information in an interesting method which is cartoons.

Apart from these two methods that engage students in the classroom, mastery learning was used by researchers and found it to be effective. A study on the effectiveness of mastery learning was evident in a study to improve students in performing problem solving tasks for this topic (Cardellini, 2014; Mitee and Obaitan, 2015). This method involves repetition of similar problem-solving alternating with corrective activities for those who did not perform well. This repetition is done until the students' performance exceeds eighty percent correct solutions. Cardellini (2014) stressed that the mastery learning was used as an effort to emphasise the development of conceptual understanding by internalizing the steps involved considering the nature of the problem and how it is solved. Although the researcher stressed on the development of the conceptual understanding in that research, the replication of that method by teachers tend to focus more on the repetition more than conceptualizing it as a speedy method of teaching the concept. Another study was conducted in the view of enhancing the conceptual understanding by introducing the Systemic Approach This approach had a slightly different view where the concept was presented in a new order of facts unlike other researchers' method (Milenkovic, et. al., 2013). The findings showed that the problems were able to be solved by respondents of higher cognitive ability only. The researcher stressed that the content presentation in the classroom itself still needs to be looked into for a better arrangement moving from concrete to abstract and relating pre-existing knowledge to new knowledge.

Algorithmic teaching strategies

Chemistry teachers worldwide have been using simple solutions to encounter this problem, such as resorting to algorithmic teaching strategies that enable students to learn abstract topics fast (Shadreck and Enunuwe, 2017; Molnar and Hamvas, 2011). Some of the characteristics of algorithmic strategies to teach mole concept include memorisation of steps and techniques to use information given in the problem to formulate a solution to it. The concepts are learnt superficially through rote learning just to be able to solve problems. Superficial learning limits the conceptual understanding of the topic but promotes short cuts to solve problems on this topic. In other words, students learn the method of solving but not the meaning of the concept in depth. These strategies are more preferred by teachers as it helps them to simplify the abstract topic by providing simple methods to solve mole concept problems. It may be evident in enabling them to learn the abstract concept fast and solve problems systematically, but chemistry students were found to be unable to apply the knowledge acquired on mole concept in new situations as independent thinkers (Espinosa, Espana, and Marasigan, 2016).

The role of teachers is crucial as the simplifier of knowledge and source of inspiration for students but it was found to be taking responsibility for the decline in the interest and performance of students in chemistry (Sim and Arshad, 2015; Hanson, 2016). Research findings show that teachers somehow succeed in getting students to calculate these figures using memorised steps of calculations, to obtain the final answer correctly. Students tend to use these methods as they find word problems as an obstacle (Samuel, Mulenga and Angel, 2016). These algorithmic teaching strategies may be successful in producing results but meaningful learning does not occur in those situations (Cardellini, 2014; Espinosa et al., 2016; Hanson, 2016). This method of teaching does not require one to think of the meaning of the question or the concept but focuses only on producing the solution. However, when a student has no other choice or way of understanding the concept, the next best option is to depend on memorisation where rote learning occurs (Choudury, 2017). The higher level of difficulty and complexity in learning mole concept has become a barrier to the thinking process for a deeper conceptual understanding (Molnar and Hamvas, 2011). This is because it requires analytical skill because it involves a lot of mathematical skill.

Thinking abilities need to be nurtured by the teacher via suitable learning experiences in the classroom. Rickey and Stacy (2000) discussed the importance of the student thinking process in chemistry education by using a Predict-Observe-Explain (POE) task as the instructional tool to promote thinking and students' awareness of their own ideas. This tool required students to think and come up with their own idea to predict the answer to a question posed, giving reasons for the predictions. This method involved a lot of thinking and formation of the concept actively through experience of the students. Thinking skills can be nurtured only if more time is spent on their answering sessions verbally or on paper (Sim and Arshad, 2015; Cardellini, 2014). Teaching methods that require thinking skills was found to be too demanding on teachers as it requires a longer duration of thinking time. Hence, most teachers opt for the speedy method to teach the topic.

"Know how" versus "Know what' Teaching Strategy

Various views on teaching strategies have been experimented through research as effective methods that can be used. However, there are also views from previous studies which debate on the nature of the type of method used, either one that promotes thinking using acquired conceptual understanding or one that follows memorised steps with superficial understanding. This view is based on how knowledge on mole concept is acquired by a student as a result of the teaching method. According to this view, the main concern is whether the student has acquired conceptual knowledge, procedural knowledge or both, as a result of the teaching method. Past researches have discussed about types of knowledge acquired by students and have classified them into two main categories, which are the conceptual knowledge and procedural knowledge. Conceptual knowledge is referred to as the "know-what" knowledge whereas procedural knowledge as the "know-how" knowledge (Portoles and Lopez, 2008; Ellis, 2009). Acquisition of conceptual knowledge involves meaningful learning whereby students understand the concept deeply and are able to explain the meaning. The in-depth understanding enables one to be able to apply it in new situations. In contrast to that, procedural knowledge focuses more on the method of how a task is performed but with superficial understanding of the meaning of the concept. Students know the method step by step, to obtain one final answer but are unable to explain why the steps are performed. The advantage of the use of "know what" method is that one is able to think independently and solve a problem through logical reasoning even in new situations that are different. In contrast to that, the "know how" method focuses more on the specific order of steps to solve commonly encountered problems. One who uses this method is unable to explain why the method is used but is confined to those memorized steps. In new situations that are different from the norm, one is unable to think logically how to solve it as the concept is not understood. Hence, the wide usage of algorithmic strategies for mole concept problem solving promotes a dominance of acquisition of procedural knowledge. According to Hiebert (1986), the learning process is where one should be able to perform a task, understand the task and know why the action is appropriate. There should be a relationship between action and understanding where learning is concerned (Hiebert, 1986).

The method through which a problem is solved should be systematic and organized. However, one should also understand it conceptually and "know what" is being solved using these set of steps of "know how". Past researchers have stressed that conceptual knowledge and procedural knowledge should be in the correct balance for a meaningful learning to occur (Forrester and Chinappan, 2010; Haidera, 2014; Groth, 2014; Ramful, 2015; Samuel, Mulenga, & Angel, 2016). The method of learning mole concept via mastery learning promotes a dominance of procedural knowledge as it requires a student to know how the problem is solved using a set of steps through repetition. The conceptual knowledge should be more dominant in a learning process as it is necessary in understanding of chemistry concepts to enable a student to be able to solve the problems mindfully (Serhan, 2015; Ramful, 2016; Mairing; 2017; Sujak & Daniel, 2018). The emphasis of a "know what" method is on the meaning of the concept and the thinking process on developing the meaning as well as how it is related to other concepts. On the other hand, the "know how" method enables one to perform a task in a systematic and organized method as well as efficient in using the information provided in a problem-solving task.

These issues were found to be happening now in school. The influence of teaching method on the learning process among chemistry students indicated that the learning environment created by the teacher is crucial in how students learn the concept. Students taught by the same teacher might have similar or different method of problem-solving skills. This can be seen in a study done on 12 form four students to explore knowledge construction on mole concept by the author. Data was collected using mind maps drawn by the students to explain what they understand about mole. Students then were interviewed to clarify their mind maps. Qualitative analysis of the mind maps and interviews as triangulation showed that students had six types of problem-solving methods.

The first method is the random substitution method where the student had the ability to write down the formula correctly, but substituted incorrect values into the formula, not knowing how to apply the formula. It indicated that the student was able to recall the formula learnt but was not able to apply appropriately. The second method was systematic step solving method where students who showed a very systematic, neat, and precise steps of problem solving started by writing down the formula, followed by substitution without any extra verbal information or reasoning. The third was number manipulation method where students picked numbers from the question and manipulated incorrectly with incorrect formula. These students could not recall the formula or the meaning of the concept but were aware that the steps require certain numerical values. Hence, they substituted any numerical value into a formula but not the appropriate ones. These three methods showed that students were trained on how to solve the problem with a set of memorized steps but unable to apply the method in new situations. These traits are similar to the descriptions of the algorithmic method of problem solving.

The fourth method - the "logical reasoning" method are those who read the question and tried to reason out how to solve the problem with correct reasoning and correct formula written later on as the working. They were able to identify any mistakes made by checking if the answer was logical or not. Although the questions were given with new contextual situations, they were able to use logical reasoning to solve it. The fifth method - "Formula independent" method is where the students solved the problems without any formula written down the working. They started working out by substituting the values right away into correct relationship of numerical equations. The formula was in their mind and they were driven through the recall of the meaning of the concept. Finally, the sixth method was the "verbal emphasis" where students read out every piece of information in the question repeatedly stressing on important words. They also reasoned out points that were not shown in the formula and made an effort to read the questions again to check while working on the problems half way through. These three characteristics portrayed more reasoning during problem solving.

These traits of the problem-solving method can be classified into two big themes based on past research findings. The two themes that emerged are algorithmic method and reasoning method. The categories random substitution (RS), systematic step solving (SS) and number manipulation (NM) categories show characteristics of the algorithmic method whereas logical reasoning, (LR), formula independent (FI) and verbal emphasis (VE) show characteristics of the reasoning method (Espinosa et. al., 2016). The classification of the six categories into the two main themes is shown in Figure 1 below.

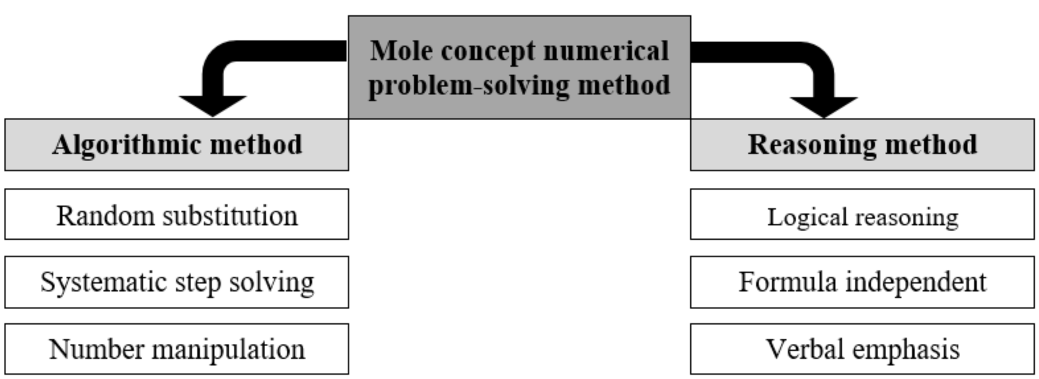

Figure 1. Classification of the two themes, "algorithmic method and "reasoning method"

Conclusions and implications for teaching

The use of a concrete prior knowledge as the foundation to build up new knowledge shows better understanding of the concept. The relevant prior knowledge was used during the expansion of ideas on problem solving. Thinking opportunities were encouraged during this phase is evident in enhancing the conceptual understanding. On the other hand, students who were taught on systematic steps of problem solving through repetition showed a more organised and systematic problem-solving steps. However, past researchers have stressed that conceptual knowledge and procedural knowledge should be in the correct balance for a meaningful learning to occur (Forrester & Chinappan, 2010; Haidera, 2014; Groth, 2014; Ramful, 2015; Samuel, Mulenga, & Angel, 2016).

As a result of the concerns of educationists from the findings of their study, various strategies have been experimented in the quest to promote meaningful learning. Those research findings can be used to identify important elements of the learning process of abstract topics such as mole concept. However, past research findings found that teachers teach this topic based on their understanding of the concept developed during their school days, via traditional and algorithmic strategies. Weak foundation of the teachers itself stands as a hurdle for students' understanding of the concept (Sim and Arshad, 2015; Hanson 2016). Teachers should make an effort to move towards the implementation of twenty first century classroom by understanding the important elements in encountering abstract topics. A well-planned teaching strategy should be adopted considering some of the important elements from findings of this study as well as the previous researches to enhance meaningful learning.

In this study, it is evident that the following elements are essential for a meaningful learning to occur. Firstly, it is important to embark the abstract topic on concrete examples for a better understanding of the concept. The use of constructivist strategies to build up new knowledge on prior knowledge can be done by identifying a suitable analogy or by relating it to their daily life in a contextual manner. A contextual prior knowledge is able to enhance students' understanding. For example, the use of real-life objects and scenario of counting a dozen pencils engaged students into the analogical concept of Avogadro's constant, which is a constant to represent a certain number of objects. The students will be able to develop a mental imagery of the new concept by comparing the known concept. Although type of particles is their prior knowledge, the teacher is starting an abstract concept using another abstract concept that is unseen. It requires students' imagination to be able to understand the new concept which may be more difficult than simple objects like pencils. Furthermore, the concept is further expanded on this shaky foundation as a starter.

Secondly, the need to expand the concept engaging students in a thinking activity enables them to develop the concept meaning actively. For example, the use of a known "part and whole" concept to calculate simple values are introduced before progressing slowly in ascending difficulty level. They use thinking of how to solve based on the meaning of the concept. Students who are introduced to the formula straight away, to explore big numbers show algorithmic strategies of problem solving. The need to understand the concept, the "know what", is necessary to be prioritized besides the method of problem-solving steps, the "know how". The 'know what" requires students to think in order to plan strategies of problem solving. Both "know what" and "know how" aspects should be considered during the planning of students' activities. Thus, an activity of mastery of problem-solving should be followed up after the conceptual understanding is developed. If the "know how" precedes the "know what", students may be too dependent on step-by-step problem solving with less thinking to develop the conceptual understanding.

Thirdly, teachers need to find strategies to gain students' interest as well as engage students actively in the lesson. The activities should involve all students, of mixed ability group, to participate actively using teaching aids that gain students' interest. The development of the concept should involve students in a two-way student-teacher interaction in order to involve them in the lesson. The Malaysian Ministry of Education is continuously conducting in-service courses on twenty first century learning skills for teachers. Hence, teachers should apply the methods from those trainings in order to plan and conduct suitable engaging activities according to their students' level. Furthermore, with the advancement in the development of technology, the ministry has equipped schools with various facilities such as computers, projectors and internet access to create more student engaging activities. These facilities can be used wisely by teachers with proper planning considering the essential elements to promote meaningful learning of abstract concept. The use of technology enables the viewing of particles that are unseen in the form of animated objects to enhance their understanding. Abstract concepts can also be taught in the form of games or interactive activities such as quizzes to create student-centered learning environment in schools. Rural schools in the interior that do not have technology still have these essential elements to create student engaging activities as alternatives.

Last but not least, the lesson should include thinking opportunities to enable students to understand the concept and sufficient thinking time should be given. Mole concept may be abstract in nature with mathematical aspects integrated within it, but teaching the topic is not something new encountered by teachers as it has been analysed over the decades with recommendations on how to make it meaningful.

REFERENCES

Akcay, S. (2016). Analysis of analogy use in secondary education science textbooks in Turkey. *Educational Research and Reviews*, 11(19), 1841-1851.

Cardellini, L. (2012). Chemistry: Why the subject is difficult? *Education Quimica*, 242. Universidad Nacional Autonoma de Mexico.

Cardellini, L. (2014). Problem solving: How can we help students overcome cognitive difficulties. *Journal of Technology and Science Education*, 4(4),237.

Choudury, U. (2017). Undergrads who depend on rote learning struggle with Chemistry. Retrieved from: braingainmag.com website: https://www.braingainmag.com/

Cobern, W. W. (2012). *Contextual constructivism: the impact of culture on the teaching and learning of science*. In K. G. Tobin (Series Ed., 2012), 4, 360.

Ellis, R. (2009). Corrective feedback and teacher development. *L2 Journal*. 1(1), 3-18.

Espinosa, A. A., Espana, R. C. N., & Marasigan, A. C. (2016). Investigating pre-service chemistry teachers' problem-solving strategies: Towards developing a framework in teaching stoichiometry. *Journal of Education in Science, Environment and Health*, 2(2), 104-124.

Faruji, L. F. (2012). The relationship between implicit and explicit knowledge and second language proficiency BRAIN. *Broad Research in Artificial Intelligence and Neuroscience*, 3(1), 1-28.

Forrester, T., & Chinappan, M. (2010). The predominance of procedural knowledge in fractions Paper presented at the Shaping the future of mathematics education: *Proceedings of the 33rd* *annual conference of the Mathematics Education Research Group of Australasia*. Fremantle: MERGA.

Gafoor, K. A., & Shilna, V. (2015). Perceived difficulty of *chemistry units in Std IX for students in Kerala stream calls for further innovations.* Paper presented in Innovations in pedagogy and curriculum: Theory to Practice GBCTE, Kerala, 10th & 11th April 2013

Gafoor, K. A., & Shilna, V. (2013). Role of concept cartoons in chemistry learning. *Two day Seminar on Learning Sciences by Doing-Sciencing, December 5th & 6th 2013.*

Gkitzia, V., Salta, K. & Tzougraki, C. (2011). Development and application of suitable criteria for the evaluation of chemical representations in school textbooks. *Chemistry Education Research and Practice,* 12, 5-15.

Groth, R. E. (2014). Prospective teachers' procedural and conceptual knowledge of mean absolute deviation. *The Research Council on Mathematics Learning*, 6(3), 51-69.

Haidera, H., Eichler, A., Hansen, S., Vaterrodt, B., Gaschler, R., & Frensch, P. A. (2014). How we use what we learn in Math: An integrative account of the development of commutativity. *Frontline Learning Research*, 1, 1-21.

Hanson, R. (2016). Ghanaian teacher trainees' conceptual understanding of stoichiometry. *Journal of Education and e-Learning Research*, 3(1), 1-8.

Hiebert, J. (1986). *Conceptual and procedural knowledge*: The case of mathematics (J. Hiebert Ed.): Lawrence Erlbaum Associates.

Hiebert, J. & Lefevre, P. (1986). *Conceptual and Procedural knowledge in mathematics: An introductory analysis*. Hillsdale NJ: Erlbaum.

Kimberlin, S., & Yezierski, E. (2016). Effectiveness of inquiry-based lessons using particulate level models to develop high school students' understanding of conceptual stoichiometry. *Journal of Chemical Education*. (93), 1002−1009.

Kondakci, E. U. & Aydin, Y. C. (2013). Predicting Critical Thinking Skills of University Students through Metacognitive Self-Regulation Skills and Chemistry Self-Efficacy. *Educational Sciences: Theory & Practice*, 13(1), 666-670.

Lee, K. W. L., Tang, W. U., Goh, N. K., & Chia, L. S. (2001). The predicting role of cognitive variables in problem solving in mole concept. *Chemistry education: Research and practice in europe 2001*, Vol. 2(No. 3), pp. 285-301.

Mairing, J. P. (2017). Thinking process of naive problem solvers to solve mathematical problems. International Education Studies, 10(1), 1-10.

Milenkovic, D., Segedinac, M., Hrin, T. & Cvjeticanin, M. (2014). Increasing high school chemistry students' performance and reducing cognitive load through an instructional strategy based on the interaction of multiple levels of knowledge. *Journal of Chemical Education*, 91(9), 1409-1416.

Milenkovic, D., Segedinac, M., Hrin, T. & Cvjeticanin, S. (2014). Cognitive load at different levels of chemistry representations. *Croatian Journal of Education*, 16(3), 699-722.

Ministry of Education (2013). *Malaysian Education Blueprint*. Retrieved from: https://www.moe.gov.my/menumedia/media-cetak/penerbitan/dasar/1207-malaysia-education-blueprint-2013-2025/file

Ministry of Education (2014). Retrieved from: https://www.moe.gov.my/en/muat-turun/pekeliling-dan-garis-panduan/ikhtisas/1999

Mitee, T. L., & Obaitan, G. N. (2015). Effect of Mastery learning on senior secondary school students' cognitive learning outcome in quantitative chemistry. *Journal of Education and Practice*, 6(5), 34-38.

Molnar, J., & Hamvas, L. M. (2011). LEGO Method-New strategy for chemistry calculation. *US-China Education Review*, 7, 891-908.

Pienta, J. N., Cooper, M. M. & Greenbowe, T. J. (2005). *Chemists' Guide to Effective Teaching. Prentice Hall*. Prentice Hall, 1st edition.

Portoles, J. J. S., & Lopes, V. S. (2008). Types of knowledge and their relations to problem solving in science: directions for practice. *Educational Sciences Journal*, 6, 106-112.

Rahman, M. M., Salleh, M. A. M., Rashid, U., Ahsan, A., Hossain, M. M., & Chang, S. R. (2014). Production of slow release crystal fertilizer from wastewaters through struvite crystallization – A review. *Arabian Journal of Chemistry*, 7, 139-155.

Ramful, A., Bedgood, D., & Lowrie, T. (2016). A collaborative endeavour between mathematics and science educators: focus on the use of percent in chemistry. *European Journal of Mathematics and Science Education*, 4(2), 196-213.

Richland, L. E., & Simms, N. (2015). *Analogy, higher order thinking, and education.* WIREs Cognitive Science. John Wiley Ltd.

Rickey, D., & Stacy, A. M. (2000). The role of metacognition in learning chemistry. *Journal of Chemical Education*, 77(7), 915.

Samuel, K., Mulenga, H. M., & Angel, M. (2016). An investigation into challenges faced by secondary school teachers and pupils in algebraic linear equations: A case of Mufulira District, Zambia *Journal of Education and Practice*, 7(26).

Serhan, D. (2015). Students' understanding of the definite integral concept. *International Journal of Research in Education and Science*, 1(1), 84-88.

Shadreck, M., & Enunuwe, O. C. (2017). Problem solving instruction for overcoming students' difficulties in stoichiometric problems. *Acta Didactica Napocensia*, 10 (4), 69-78.

Sheau, H. C. (2016). Wither the concepts of mole and concentration: Conceptual confusion in applying M1V1=M2V2. *Universal Journal of Educational Research*, 4(5), 1158-1162.

Sim, W. S. L., & Arshad, M. Y. (2015). Inquiry practices in Malaysian secondary classroom and model of inquiry teaching based on verbal interaction. *Malaysian Journal of Learning and Instruction*, 12, 151-175.

Singh, M. & Sachdeva, S. (2014). Cognitive assessment techniques. 7(2), *International Journal of Information Technology and Knowledge Management*, 108-118.

Sopandi, W., Kadarohman, A., Rosbiono, M., Latip, A., & Sukardi, R. R. (2018). The courseware of discontinuous nature of matter in teaching the states of matter and their changes. *International Journal of Instruction*, 11(1) 61-76.

Sujak, K. & Daniel, E. G. S. (2018). Understanding of Macroscopic, Microscopic and Symbolic Representations Among Form Four Students in Solving Stoichiometric Problems. *Malaysian Online Journal of Educational Sciences***,** 5(3), 83-96.

Surif, J., Ibrahim, N. H. & Mokhtar, M. (2012). Conceptual and procedural knowledge in problem solving. *International Conference on Teaching and Learning in Higher Education (ICTLHE 2012)*. 56, 416-425.

Taber, K. S. (2013). Three levels of Chemistry Education Research. *Chemistry Education Research and Practice*, 14, 151-155.

Treagust, D. F., Chittleborough, G., & Mamiala, T. (2003). The role of submicroscopic and symbolic representations in chemical explanations. *Multiple Representations in Chemical Education, Models and Modeling in Science Education*, 25(11), 1353-1368.