CHEMICAL PROBLEM-SOLVING COMPETENCY OF OPEN-ENDED PROBLEMS AIMING TO IMPROVE HIGHER ORDER THINKING SKILLS (HOTS): AUTHENTIC PRACTICE

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Abstract

Problem-solving is a thinking task of constructing an understanding and applying of new knowledge during a learning process but real world required a competent global citizen, one who is knowledgeable, able to think critically and creatively with problem solving skills that may enable him to communicate with the rest of the world. Therefore, the role of formal education is not merely to transfer knowledge but also to apply it to generate future leaders with higher order thinking skills in solving problems in real life. Unfortunately, most of the school students are facing difficulties in solving open-ended problems in Chemistry. This paper discusses the possibilities of successful problem-solver in Chemistry are determined by a student's Chemical problem-solving competency. At present, school teachers are lack of specific instructions in using authentic practice as contexts for learning to promote the higher order thinking skills in solving non-routine problem. Learning becomes more meaningful when students can *incorporate their existing knowledge and experience to solve non-routine problems in the real world. Therefore, Model of Authentic Chemical Problem-solving Competency is proposed to be developed in order to create an instructional strategy incorporating an authentic practice to enhance student's problem-solving competency in Chemistry. The authors are currently researching to develop Model of Authentic Chemical Problem-solving Competency for school students.*

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1.1 INTRODUCTION

Problem- solving is something that we have to do in our life everyday as a student, worker or leader. Problem-solving is a generic skill that needs to be acquired in ensuring success in learning and working (Yunus *et al.*, 2006). Problem solving also includes an attitude or predisposition toward inquiry as well as the actual processes by which individuals attempt to gain knowledge.

Problem-solving in students' perspective is more focused on answering problems posed by teachers or prescribed in a written assessment. In contrast to the real-life problems, most problems presented at school tend to be well-defined and focused on one correct solution , instead of open-ended (Reid & Yang, 2002). Problem-solving expects students to involve with the thinking operations of analysis, synthesis, and evaluation which are considered as higher-level thinking skills (HOTS).

Now we are facing with a globalized world that is full of information explosion and rapidly changing technology. According to The Organisation for Economic Co-operation and Development (OECD, 2013), it stated that the method how individuals solve problems has changed in response to current demands. Once upon a time, we need a dictionary to find the translation of word from one language to another, but now the immediate search is no longer from paper dictionary but via online translator using the search engine navigation. Thus, the approach used to solve the problems in the learning process must also suit the current realities of life.

Meaningful learning will provide students with problem-solving competency to ensure that students can develop a deep understanding (Suryawati *et al.*, 2010). A student who has been granted an early exposure on problem-solving competency will move on to higher education institutions and their future career with the efficiency, capacity, speed, skills, attitudes, motivation and problem-solving experience that is authentic and meaningful (OECD, 2013). In the view of the high expectation of people in a world of conflicting and competing values and unevenly distributed resources, modern life has turned into a continuous process of problem solving and decision making (Zooler, 1991, Jensen *et al.,* 2014). Therefore, aspiration of successful problem solver nurtured in formal education will meet this expectation to generate number of global future leader who are would be competent in solving real-life problems.

1.2 HIGHER ORDER THINKING SKILLS AND PROBLEM-SOLVING IN CHEMISTRY

Problem- solving in learning chemistry involves a thinking task as students need to construct a deep conceptual understanding, then apply the formulae and concepts to real-life situation. Deep understanding requires higher-order thinking for students to construct new knowledge or concepts in their cognitive map. According to Malaysia Curriculum Development Centre (2012), "Higher-order" problems promote learning because these types of problems require students to apply, analyze, synthesize, and evaluate information instead of simply recalling facts.

Resnick (1987) characterized higher-order thinking (HOT) as “non-algorithmic.” Stein and Lane (1996**)** describe higher-order thinking skills (HOTS) as “the use of complex, non-algorithmic thinking to solve a task in which there is not a predictable, well-rehearsed approach or pathway explicitly suggested by the task, task instruction, or a worked out example”. If we want students to develop the capacity to think, reason, and solve problems then we need to start with high-level, cognitively complex tasks. Therefore, those three higher levels of Bloom’s taxonomy (analyze, evaluate, and create) require higher-order thinking skills to solve open-ended, ill-defined and non-routine problems (Zoller, 1993). Thus the process of teaching and learning activities that enhance the injection of higher order thinking skills will lead students to be more familiar and successful in solving non-routine problems in Chemistry.

In the current global education issue, higher order thinking skills are required in solving a non-routine problem (Goodson & Rohani, 1998; Jensen *et al.*, 2014). Hence, Higher-order thinking skills of students can be improved by providing a learning environment and assessment in promoting scientific understanding (Jensen *et al.*, 2014). Higher-order thinking skills can turn students’ time inside and outside of class into productive learning time, rather than bouts of rote memorization.

Our greatest shortcoming in education these past few years has been ignoring the brain research that is richly available to us which affirms that implementing multi-sensory activities, pursuing meaningful and authentic tasks, exploring a variety of skills with real world and authentic applications is optimal learning and that it needs to be practiced regularly. By engaging the students with Authentic learning environment**,** then they manage to apply their higher level thinking skills in order to find out the solution for the open-ended and non-routine problems (Lombardi & Oblinger, 2007). Higher-order thinking skills are important to produce future scientifically trained generation who are competent enough to think rationally, critically and creatively to solve their real-world problems successfully (Jensen *et al.,* 2014). As a result, application of the higher order thinking skills will lead to the integration of knowledge and experience of the students in problem solving explanation, decision making, performances and products in their future career undertaking.

1.3 STUDENTS' DIFFICULTIES IN CHEMICAL PROBLEM-SOLVING

Chemistry is particularly conceived by many as a difficult subject to teach and learn (Johnstone, 1991; Nakhleh, 1992; Taber, 2002). By its nature, chemistry deals with a sub-microscopic world as well as with an observable or phenomenological world, both of which are communicated through the use of symbols. Johnstone (1982) proposed a model of thinking in chemistry that consists of three levels: the macro, the micro, and the symbolic.

Researchers in Science Education have noted that school and university students performed poor in conceptual and open-ended questions in Chemistry problem solving ability (Osborne & Cosgrove, 1983; Nakhleh, 1993 ; Johari *et al.,* 2014). Difficulties in solving the problems arise due to certain factors such as students familiarity with solving only the routine problems, poor conceptual understanding to solve open-ended problems, lack of problem-solving skills and limited use of specific instruction module to teach Chemical problem–solving skills to school student (Gayon, 2008; Johari *et al.,* 2013, Boži & Tramullas, 2014).

1.3.1 Focus In Solving The Routine And Algorithm Problems

Most students are familiar in solving routine and algorithm problems. (Jensen *et al*., 2014). It is generally accepted that the first two levels of revised Bloom's (Anderson *et al*., 2001), *remember* and *understand* require only minimal levels of understanding and are considered lower-order cognitive skills (Crowe *et al.*, 2008; Zooler, 1993; Jensen *et al.*, 2014).

According to Reid & Yang (2002), most problem-solving in Chemistry tends to be algorithmic in nature, while problems in life tend to be very open ended. If the students can recall the method of tackling the logarithm problem, no problem remains and it becomes exercises where one set of numbers is substituted for another or if students are able to solve the given question immediately without any difficulties. However, in real life, problems may have quite different shapes which are not limited to algorithmic manipulation and which demand a higher thinking skill for their solution (Wood, 2006). Real-life problems tend to be very open-ended with so many possible solutions (Hanney, 2014).

Several researches have shown that there is a gap between conceptual understanding and algorithmic problem solving in chemistry students from high school to graduate school (Osborne & Cosgrove, 1983; Johari *et al.*, 2013). Most students could solve algorithmic chemical problem successfully compared to conceptual problem (Johari *et al.*, 2013). Students are commonly emphasized with learning rules and algorithm in solving the computational problem which considered as low order thinking skills (Gayon, 2008). Even most questions in standard Malaysian national assessments require students with low order thinking skills to solve the questions. This scenario has contributed to the poor achievement in Programme for International Student Assessment (PISA) due to most of Malaysian students are familiar with lower-order and intermediate cognitive skills of problems which include the level of knowledge, comprehension and application only (Malaysian Ministry of Education, 2012).

1.3.2 Poor In Solving "Word" and "Open-ended" Problems in Chemistry

Problem familiarity is one factor that contributes to the successful problem-solving ability of students in chemistry. The students' performance in problem familiarity shows that the students lack in exposure to word and open-ended problems (Gayon, 2008, Johari *et al.*, 2013). Non-routine problems are usually presented in the form of open-ended problems and ill-defined. Open-ended problem can be used to assess whether the student has truly grasped a chemical concept (Scottish QRA, 2012). Only small number of Malaysian university students can solve open-ended problem successfully and majority cannot because of their inability to understand the concepts of underlying the problems given (Johari *et al.*, 2013). Word problems that are more contextual and experiential illustrating real-life problem situations are more relevant to the students.

Reid & Yang (2002) noted that familiarity gives a great confidence which comes from experience. Criteria for success in solving open-ended problems are very different from the more common closed problems because students are so used in getting 'the correct answer' in academic closed problems but there is no unique correct answer in open-ended problem (Wood, 2006). To develop chemical problem-solving competency, this open-ended question presents a real-life context that is interesting and relevant to the students (Scottish QRA, 2012; OECD, 2013)

1.3.3 Lack of Chemical Problem-Solving Skills

Several researchers have identified that school and university students lack problem solving skills (Gayon, 2008; Johari *et al*., 2012). Malaysian University students are lack generic skills in problem solving and specifically in definition and formulation of problems, in generation of alternatives subscale, in decision making and implementation and verification of the Poor achievement of Malaysian students in PISA 2009 is also due to lack of problem solving skills because students have the inability to comprehend the questions in the form of long text that require them to do interpretation, reflection and real life based assessment (Malaysian Ministry of Education, 2012). solution (Yunus *et al.*, 2006). Gayon (2008) found that school students performed poorly on applying specific problem-solving strategies and still cannot perform the basic steps of the procedure.

It becomes more tough for the teacher to teach problem solving in chemistry because this task involves exposure to a problem-solving strategy and other problem-solving skills(Boži & Tramullas, 2014).

1.3.4 Lack of Specific Instruction of Chemical Problem-solving

Research evidence has not only discovered that most students lack of problem solving skills but also the teachers have a limited specific or formal instruction for teaching problem-solving in Chemistry among school students in promoting appropriate and effective classroom techniques and practices to foster meaningful learning (Herrington, 2000; Bulte, & Driel, 2009). Most of the existing instruction modules are developed for university students (Anderson, 1993; Wood, 2006; Boži & Tramullas, 2014). One approach to identify and describe the generic steps or stages problem solvers go through in struggling with the problem is by developing the model of problem-solving ((Prins *et al.,* 2009). Then the teacher or educator can create an instructional strategy based on the developed model to improve students' problem-solving abilities (Herrington & Herrington, 2008; Suryawati *et al.*, 2010). Therefore, authors proposed to find out the new approach and strategy in developing an instructional model of problem-solving to put this agenda into practice and reality in learning Chemistry.

1.4 MODEL OF AUTHENTIC CHEMICAL PROBLEM-SOLVING COMPETENCY

Due to the some identified difficulties in problem-solving among students, some researchers have developed Model of problem-solving. Dewey's model of problem-solving (1910) and Polya's model (1946) are considered as most popular models for many years. The model of problem solving developed by Wheatley (1984) which was used to teach chemistry (Bodner & Pardue, 1995) is a cyclic, reflective and might appear irrational because it differs from the approach a subject matter expert would take to the task. The limitations in Polya's model is due to the assumption that problem solver begin by "understanding the problem" and appropriate to solve routine or algorithm exercise. In the other models proposed by Dewey and Wheatley found out that "understanding the problem" arises toward the end of problem-solving process (Bodner & Herron, 2002).

Psychological Model of Chemistry Problem Solving by Ashmore *et al.* (1979) divided the problem solving process into four stages: discern the question, choose the appropriate information, combine independent information, and comments. Then, Lee and Fensham (1996) have identified seven processes in problem-solving and this model shown a more consistent result than either to Polya's , Dewey's and Wheatley's model of problem solving. All of the these models have some constraints including non- real world relevance, non-contextual, less fun and out of date in solving problem collaboratively using information technology.

Model of Problem-solving by Lee and Fensham (1996) is appropriate to solve open-ended or non-routine problems. This model is selected due to certain justification that is appropriate to solve open-ended and ill-defined problems in Chemistry with the systematic steps to illustrate the thinking process involved. This model has identified seven distinguishable processes in problem-solving. Application of this model will enable researcher to observe the process of solving the problem which is more systematic and detailed. The problem-solving process is much more important than the consequence.

Unfortunately, the existing models of problem-solving are only focusing on the skills and meta cognitive process in solving the problems without considering the problem solver's knowledge, attitude, motivation and real-world relevance. Recently, global success of students in problem-solving are influenced by their collaborative problem-solving competency and this competency is applicable in their future workplace (OECD, 2013). Even when we are looking deeply into the crucial development of problem-solving in education at present, there is a lack of specific knowledge base to teach problem-solving competency using authentic practices such as contexts to improve the higher order thinking skills. Therefore, to meet the expectation of this new era of education, it is essential to develop Model of Authentic Chemical Problem-solving Competency in order to create an instructional strategy with an authentic practice to assist the educators and students in providing them with the systematic strategy, process and conditions in teaching problem-solving in Chemistry.

1.5 CHEMICAL PROBLEM-SOLVING COMPETENCY IN AUTHENTIC LEARNING

In this concept paper, Chemical problem-solving competency has been taken as a combination of observable knowledge, skills, attitudes, efficiency, speed and motivation that can be measured before, during and after the process in solving open-ended, ill-defined and non-routine Chemistry problem based on students' actual performance. This Model of Authentic Chemical Problem-solving Competency will assist to improve higher order thinking skills among students to solve open-ended problem in Chemistry. Is this Authentic practice is an appropriate and effective learning approach to improve level of thinking skills among students that enable them to solve open-ended, ill-defined and non-routine problem in Chemistry?

Authentic learning can be constructed as a form of real life learning. Authentic learning is contextual learning approach that can improve higher-order thinking skills and problem-solving competency as well, thereby facilitating chemical problem-solving among students (Herrington, 2000; Suryawati *et al.*, 2010). Authentic learning emphasize on activities related to real life to solve ill-structured problems collaboratively (Herrington & Herrington, 2008). According to Lombardi & Oblinger (2007), Authentic learning typically focuses on real-world, complex problems and their solutions, using role-playing exercises, problem-based activities, case studies, and participation in virtual communities of practice.

Authentic learning engages all the senses allowing students to create a meaningful, useful and shared outcome. They are real life tasks, or simulated tasks that provide the students with opportunities to connect with the real world (Prins *et al.*, 2008). It is a style of learning that encourages students to create a tangible, useful product to be shared with their world. Moreover, this approach is appropriate to improve student’s problem-solving skill and ability because Authentic instruction standards emphasizes on higher order thinking, depth of knowledge, connectedness to the world beyond the classroom, substantive conversation, social support for achievement (Newman & Wehlage, 1993). Reportedly, some students say that they are also motivated by solving real-world problems (Lombardi & Oblinger, 2007).

Learning-by-doing is generally considered the most effective way to learn (Herrington & Herrington, 2008). This, also referred to as authentic learning environment, is created by providing real-world and relevant activities to solve the ill-defined problems collaboratively. It should also be supported with computer and online learning. Recently, collaborative problem-solving competency is another dimension to be measured in the assessment in PISA 2015 (OECD, 2013). Hence, it is important to include this collaborative element in the model.

Non-routine problems can be solved by a various approaches and can produce many solutions depending on the knowledge and experience of the problem-solvers. Therefore students should be given the opportunity to engage in real world activities to solve complex, non-routine or ill-defined problems. Glover *et al.* (1990) asserted that most significant real-world problems are ill-defined, tend to be multi-faceted and open ended. Ill-defined problem will involve non-routine challenge that normally related with the real life situation that challenging the mind of an individual because it requires a high level of thinking (Li *et al.*, 2013). Without deep reasoning and interpretation, students will find a difficulty to solve the ill-defined problem. Therefore, learning activity and problems that related with real-world will enhance the students’ deep understanding (Newman & Wehlage, 1993).

1.6 CONCLUSION

Students normally encounter well-structured (story-like) problems, which are inconsistent with the nature of the problems that they will need to learn to solve in their real life. Higher -order thinking skills are activated when students at any age encounter unfamiliar problems, uncertainties, questions or dilemmas. The authentic learning environment is created by providing real-world relevance activities to solve the ill-defined problems collaboratively and supported with computers and online learning. This Model of Authentic Chemical Problem-solving Competency will be developed in order to create an instructional strategy with an authentic practice to assist the educators and students in providing them with the systematic strategy, process and condition in teaching problem-solving in Chemistry.

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