EFFECT OF AUTHENTIC CHEMISTRY PROBLEM SOLVING COMPETENCY IN SOLVING OPEN-ENDED PROBLEMS

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To my dearest supportive husband, Mohd Nor bin C. Lah

&

My beloved mom and dad
(Al-Fatihah)

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ABSTRACT

Problem-solving competency assists students when they apply their scientific knowledge, experiences and skills in the learning process. This study was conducted in order to develop module for authentic chemistry problem-solving competency (MAC-PSC). The module can be used to enhance the development of problem-solving competency when solving open-ended problems in chemistry. Prior to the development of this module, a preliminary study (n=112) was conducted to determine the levels of Chemistry problem-solving ability and skills among students. In addition, this study also investigated process and underlying factors involved in solving open-ended problems when learning Chemistry. Results showed that the students who were involved in the study had a moderate level of chemistry problem-solving ability and skills. Findings from the preliminary study were used to design and develop the Module for Authentic Chemistry Problem Solving Competency (MAC-PSC). A quasi experiment with a control group (n=47) and an authentic group (n=46) was adopted in the implementation phase. After using the Module (MAC-PSC) for six weeks, performance of students in pre and post chemistry problem-solving ability test (CPSAT) showed a significant positive effect. In addition students' development of Chemistry problem-solving competency to solve open-ended problems was also being investigated. This study identified these factors; (1) application of appropriate problem-solving skills, (2) deep conceptual understanding of scientific knowledge, (3) engaged in real life tasks, (4) collaborative problem-solving, (5) refer to experts, (6) accessible to multiple resources, (7) familiar with solving open-ended problems and (8) reflective writing practice, to be the key elements that catalysed the development of problem-solving competency when learning Chemistry. These key elements are useful for educators when designing learning strategies aimed at enhancing problem-solving competency among school students.

ABSTRAK

Kompetensi menyelesaikan masalah membantu pelajar apabila mereka mengaplikasikan pengetahuan saintifik, pengalaman dan kemahiran dalam proses pembelajaran. Kajian ini dijalankan untuk membangunkan "Module for Authentic Chemistry Problem Solving Competency (MAC-PSC)". Modul ini digunakan untuk meningkatkan pembangunan kompetensi menyelesaikan masalah terbuka dalam Kimia. Sebelum pembangunan modul ini, satu kajian awal (n = 112) telah dijalankan untuk menentukan tahap keupayaan dan kemahiran penyelesaian masalah Kimia dalam kalangan pelajar. Di samping itu, kajian ini juga mengkaji proses dan faktor utama yang terlibat dalam menyelesaikan masalah terbuka semasa mempelajari Kimia. Keputusan menunjukkan bahawa para pelajar yang terlibat dalam kajian mempunyai keupayaan dan kemahiran menyelesaikan masalah Kimia pada tahap yang sederhana. Dapatan dari kajian awal ini digunakan untuk merekabentuk dan membangunkan modul "MAC-PSC". Eksperimen kuasi dengan kumpulan kawalan (n = 47) dan kumpulan autentik (n = 46) telah digunakan dalam fasa pelaksanaan modul. Selepas enam minggu menggunakan modul (MAC-PSC), prestasi pelajar dalam ujian keupayaan menyelesaikan masalah pra dan pasca kimia (CPSAT) menunjukkan kesan positif yang signifikan. Di samping itu, pembangunan kompetensi pelajar dalam menyelesaikan masalah terbuka Kimia juga dikaji. Kajian ini telah mengenal pasti faktor-faktor berikut (1) aplikasi kemahiran menyelesaikan masalah yang bersesuaian, (2) pengetahuan saintifik dan pemahaman konseptual yang mendalam, (3) menghubung kait tugasan dengan situasi kehidupan sebenar, (4) menyelesaikan masalah kolaborasi, (5) merujuk kepada pakar, (6) mengakses maklumat daripada pelbagai sumber, (7) kebiasaan dalam menyelesaikan masalah terbuka dan (8) amalan penulisan reflektif sebagai elemen-elemen utama yang menjadi pemangkin pembangunan kompetensi menyelesaikan masalah terbuka dalam proses pembelajaran Kimia. Elemen-elemen utama ini bermanfaat untuk pendidik merancang strategi pembelajaran untuk meningkatkan kompetensi menyelesaikan masalah dalam kalangan pelajar sekolah.

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LIST OF ABBREVIATIONS

PISA	-	Programme For International Students Assessment
OECD	-	The Organisation for Economic Co-operation and Development
HOTS	-	Higher Order Thinking Skills
LOTS	-	Lower Order Thinking Skills
CPSAT	-	Chemistry Problem Solving Ability Test
CPSS	-	Chemistry Problem Solving Skills
SPM	-	Sijil Pelajaran Malaysia
PSC	-	Problem Solving Competency
PSS	-	Problem Solving Skill
SSCS	-	Search, Solve, Create, Share
RLT	-	Real Life Task
ADDIE	-	Analyse. Design. Develop. Implement. Evaluate.
MOE	-	Ministry of Education
KBSM	-	Kurikulum Bersepadu Sekolah Menengah

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CHAPTER 1

INTRODUCTION

1.1 Introduction

In the formal education system, intellectual achievement is one of the main aspects, emphasized to produce global knowledgeable and competent Malaysian citizens. Intellect is an important component in the development of human capital as it is clearly stated in the Malaysian National Education Philosophy.

> *"Education in Malaysia is an on-going effort towards further developing the potential of individuals in a holistic and integrated manner, in order to produce individuals who are intellectually, spiritually, emotionally and physically, balanced and harmoniously, based on a firm belief in and devotion to God. Such an effort is designed to produce Malaysian citizens who are knowledgeable and competent, who possess high moral standards and who are responsible and capable of achieving a high level of personal well-being to contribute to the betterment of the nation, family and society."*
>
> (Malaysia National Education Philosophy, 1990)

National Science Education Philosophy (Ministry of Education Malaysia, 2005) also emphasized on how science education has played an important and significant role in Malaysia to nurture the citizens to be competitive, dynamic, robust and resilient, and able to master scientific knowledge and technological competency in the future. This is due to the rapid change in the global market, which requires competent citizens, hence, demands a transformation in Malaysian national education. The role of formal education in school is not merely to transfer knowledge but also to apply the knowledge to produce future generation with Higher Order Thinking Skills (HOTS) to solve complicated problems in the real world especially in Malaysia.

In addition, by the year 2025, Malaysia government aims that features universal access all the way through to secondary education, will produce students who perform in the top third of international assessments, to provide equal and quality educational opportunities for all students (Malaysian Blue Print, 2012). However, till to date, the performance of Malaysian students in Programme for International Students Assessment (PISA, 2006, 2012) in problem solving tests are below the global average score as compared to other countries due to low application of higher order thinking skills in solving the problems (Yunus et al., 2006).

In order to compete with the best in the world, the education system must develop young Malaysians, who are knowledgeable, able to think critically, innovative and creative, have leadership qualities and problem solving skills that will enable them to communicate with the rest of the world. In conjunction to this, problem-solving competency becomes a central objective within the educational programmes of many countries such as Shanghai (China), Hong Kong, Singapore, Japan and Finland because the acquisition of increased levels of problem-solving competency provides a basis for future learning, for effective participation in society and for conducting personal activities (OECD, 2014).

Students are exposed to the various learning styles and approaches to induce the HOTS in constructing new knowledge and experience in life. Therefore, Malaysian education sector realizes that students need to be engaged with HOTS in

problem solving tasks during formal education assessment and authentic practice. As a result, education in Malaysia is moving on to shift the trend from routine learning process in the classroom with text books into an active, meaningful and authentic learning in order to produce scholars that are competent to solve real-world problems (Malaysia Ministry of Education, 2012).

Due to transformation in education, Malaysia focuses on developing human capital that can compete globally. Malaysia Education Blueprint (2012) stated that the goal and purpose of the education system was to equip the local students holistically to allow them to succeed in the 21st century, with all of the opportunities and challenges in this new era. To achieve the concerned goal, achievement among Malaysian students especially in Science and Mathematics must be equal or higher than their counterparts in other developing countries such as Singapore and Finland. Hence, to face these challenges, students must be equipped with sufficient and updated scientific knowledge, competency and new emerging skills in order to compete with the rest of the world**.** In science education, it is crucial to foster the students' problem solving competency in order to solve real world problems. Therefore, the nation's aspiration to develop efficient citizens by enhancing problem solving competency among students is a crucial issue in science education research.

1.2 Research Background

Problem solving in learning Chemistry involves a thinking task as students need to construct a deep conceptual understanding, before applying the formulae and concepts to real-life situation. Deep understanding of conceptual knowledge requires thinking skills for students to construct new knowledge or concepts in their cognitive map. Evidences from previous researchers have identified some difficulties in Chemistry problem solving that arose among school and university students (Cameron, 2002; Evi Suryawati, 2010; Mohd Nor and Nor Hidayah, 2011; Nagalingam, 2007; Nakhleh, 1993; Surif et al., 2013, 2014).

Information explosion and rapidly changing technology can play an important role in addressing the issue of problem solving competency. According to The Organization for Economic Co-operation and Development (OECD, 2013), the method on how individuals solved problems have changed in response to the current demands. Once upon a time, we needed a dictionary to find the translation of words from one language to another. However, 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 with the current realities of life. Extensive application of information communication technology (ICT) in problem solving should be integrated at school level by providing an appropriate learning module. This comprehensive learning module as a tool has the potential to catalyse the development of problem solving competency to solve open-ended problems among school students.

1.2.1 Problem Solving of Open-Ended Problems

Recent developments in problem solving have heightened the need for open-ended problems. A primary concern of problem solving is a challenge that each of us needs to encounter in our real-life situation. Most people are struggling to gain the best solution based on their knowledge, experience and even when considering the resources and facilities provided. Real-life problems tend to be very open-ended with so many possible solutions (Hanney, 2014; Reid and Yang, 2002;). A key aspect of open-ended problems may arise in certain area and can be solved by different strategies. Glover et al., (1990) asserted that most significant real-world problems were ill-defined; tended to be multi-faceted and open-ended with variety of possible approaches and outcomes. Božy and Tramullas (2014) described issues and challenges of the learning experiences due to the use of open-ended problems in a workplace simulation course in order to provide students with skills and competencies for successful inclusion into the work world. This indicates that citizens need to be able to apply what they have learnt from school or university to new situations (OECD, 2012). The study of individuals' problem-solving strengths

has provided a window into their capabilities to employ basic thinking and other general cognitive approaches to confront challenges in life (Lesh and Zawojewski, 2007).

1.2.2 Problem Solving Competency in Chemistry

Problem solving is fundamental in physical science course such as Chemistry. Chemistry is a core subject in Malaysian National Curriculum (Ministry of Education, 1983) for students in Science and Technical Stream in secondary schools. However, there have not been any remarkable improvements in the interest of students toward Chemistry. Reportedly, Education General-Director from the Ministry of Education stated that the performance of SPM candidates was dropped in 2015 by 0.08 from 5.15 to 5.08 in 2014 (BERNAMA, 2016). The same scenario occurred at the international level of Malaysian students' performance in both PISA and TIMSS that showed low level of understanding of basic concepts in Science.

The PISA 2012 problem-solving competency is defined as an individual's capacity to engage in cognitive processing to understand and resolve problem situations where a method of solution is not immediately obvious. According to OECD (2012), this competency includes the willingness to involve with such situations in order to achieve one's potential as a constructive and reflective citizen. Problem solving competency can be used to measure the achievement of student in Chemistry, therefore, most of the students whose problem solving competency scores improved or students who scored high on the problem solving protocol would do well on the Chemistry Concept Inventory (Lartson, 2013). Problem solving competency in Chemistry will contribute to a good grade in Chemistry for students in pursuing their studies because it is a key area in which students should gain experience in school through problem solving, which can support subject learning and develop skills (Holroyd, 1989; Kim and Tan, 2013). However most of the problems presented in school tend to be well-defined but real-life problems are open-ended as a domain that assessed in PISA (Lombardi, 2007; OECD, 2012).

Some key findings of the survey done in 2005 on problem-solving due to inclined performance of PISA in Science found that in most countries, more than 10% of students were unable to solve basic problems meanwhile, half of the students in OECD countries were unable to solve problems that were more difficult than basic problems (OECD, 2012). Successful problem solving indicates that students have applied the knowledge, skill and ability to discover solution in Chemistry with certain justification (Boži and Tramullas, 2014). Due to the emergence, it is essential to engage the students with open-ended problem in schools in order to develop the problem-solving competency.

1.2.3 Students' Difficulties in Chemistry Problem Solving

Students' performance in Chemistry depends on many factors and stands out to show how well a student is doing. Researchers in Science Education have noted that school and university students performed poorly in conceptual and open-ended problems in Chemistry problem solving ability (Osborne and Cosgrove, 1983; Nakhleh, 1993; Surif 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 possessed by students (Surif et al., 2013; Yunus et al., 2006). Evidence showed that there is limited availability and application of specific instruction module to teach Chemistry problem–solving skills to school students (Gayon, 2008; Surif et al., 2013, Boži and Tramullas, 2014). Then, most of researchers in education focused on the learner problem-solving ability and heuristic in the context of classroom learning environment.

Most students are familiar in solving multiple choices questions and routine problems which requires low order thinking skills (LOTS) (Jensen et al., 2014). The first two levels of revised Bloom's (Anderson et al., 2001); remember and understand, are considered as lower-order cognitive skills because they only require minimal levels of understanding and (Crowe et al., 2008; Jensen et al., 2014; Zooler,

1993). If students are able to solve the given problem immediately without any difficulties, then the problem is known as exercise, not a problem (Wood, 2006).

This trend of problem can be found in the school based and national assessments that require students with low order thinking skills to solve the problems. This scenario has contributed to the poor achievement of Malaysian students in PISA (Malaysian Ministry of Education, 2012) because they have been familiarised with lower-order and intermediate cognitive skills of problems which include the level of knowledge, comprehension and application (revised Bloom's Taxonomy, 1981). Therefore it is indicated that school students are essential to be exposed and guided to solve open-ended problem in Chemistry extensively.

Problem familiarity is a factor that contributes to the successful problem-solving ability of students in Chemistry. The students' performance in problem familiarity shows that the students have a lack exposure to open ended problems (Gayon, 2008; Surif et al., 2013). A small number of Malaysian university students cannot solve open-ended problem successfully because of inability to understand the concepts underlying the problems given (Surif et al., 2013). Open-ended problems are more contextual and experiential illustrating real-life problem situations are more relevant to the students. Reid and Yang (2002) noted that familiarity has given a great confidence which came from experience. Therefore students should learn in an environment that favours activity to experience and fosters immediate engagement (Nordstrom and Korpelainen, 2011). Criteria for success are very different in open-ended problems from the more common closed problems because students are so used in getting 'the correct answer' in academic closed problems. Hence, application of higher order thinking will nurture the students with critical and reasoning skills to justify many answer options for open-ended problems which lack in problem solving skills.

Several researchers identified that school and university students were lack of problem solving skills (Gayon, 2008; Yunus et al., 2006). Students at higher education are lack of generic skills in problem solving specifically in definition and formulation of problems, in generation of alternatives subscale, in decision making

and implementation, and verification of the solution (Yunus et al., 2006). Gayon (2008) found that school students performed poorly on applying specific problem-solving strategies and still could not perform the basic steps of the procedure.

Poor achievement of Malaysian students in PISA 2009 is also due to the lack of problem solving skills as students have the inability to comprehend the questions in the form of long texts that require them to do interpretation, reflection and real life based assessment (Malaysian Ministry of Education, 2012). If the students were not exposed with structured problem solving process in school, then how could they manage to be more competent to develop their problem solving competency in Chemistry. This problem solving competency can be developed and supported by meaningful learning process emphasised on problem solving skills.

Research evidence has not only discovered that most students are lack of problem-solving skills but also the teachers who have a limited specific or formal instruction for problem-solving teaching in Chemistry among school students. Module of Problem Solving Instruction is essential in promoting an appropriate and effective classroom techniques and practices to foster meaningful learning (Bulte and Driel, 2009; Herrington, 2000). Unfortunately, most of the existing instruction modules are developed for university students (Anderson, 1993; Božy and Tramullas, 2014; Wood, 2006). 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 enhance students' problem-solving abilities (Evy Suryawati et al., 2010; Herrington and Herrington, 2008). It becomes tougher for the teachers to teach problem solving in Chemistry because this task involves an exposure to a problem-solving strategy and other problem-solving skills (Boži and Tramullas, 2014).

Recent performance in international assessment has been measured by such as PISA and TIMSS on the effect of education in problem solving at international level. There is a gap arise in education that is designed to teach the scientific skill in student rather than provide the opportunities to apply those relevance skills to solve

the problem either in the classroom or outside the classroom. PISA's science framework (OECD, 2006) has a clear outline on how the students need to competent with those scientific skills known as scientific competency. Science subjects in Malaysia secondary school such as Chemistry is still bonding with the practical work assessment to evaluate the students in laboratory practical work. The constructs for this type of assessment emphasize on science process and manipulative skills rather than develop scientific competency to solve real life problems.

To reach at the global education standard assessment, this scientific competency is still missing in our national curriculum. Most of local school students are not competent to apply scientific knowledge and skills practically to develop scientific competency. All domains in scientific competency are closely related with application of HOTS to create the appropriate solution. Gagne (1977) stated that problem solving can be viewed as thinking process to yield new knowledge by which the students discovered a combination of previously learned rules that they can apply to solve novel problems especially in Chemistry.

Due to the educational research development to emphasize that higher order thinking skills are important in problem solving task, Malaysian Education Blueprint (Ministry of Education, 2012) has stated that one of the key attributes acquired by students to be globally competitive is thinking skills (Jensen et al., 2014). Normally open-ended problems existing in real-life often require complex solutions that can be obtained through higher thinking processes. Every student will learn how to continue acquiring knowledge throughout their lives and be able to connect different pieces of knowledge to create a new scientific knowledge. Then students will master a range of important cognitive skills including problem-solving, reasoning, creative thinking, and innovation in Chemistry. This is an area where the system has historically fallen short, with students are being less able than they should be in applying knowledge and thinking critically outside familiar academic contexts.

The importance of problem solving competency will be projected in the students' future career and real world (Boži and Tramullas, 2014; Hanney, 2014). Cotton (2003) emphasized that the need to develop problem solving competency was

due to many job perspectives which demanded advanced skills, required people to be able to learn, reason, think creatively, make decision and solve problems. Students should be given many opportunities to learn how science can solve the crucial open-ended problems (Herrington and Herrington, 2008; Herrington, 2000; Yunus et al., 2006). However, when learning and context are separated, knowledge itself is seen by students as the final product of education rather than a tool to be used dynamically to solve problems (Herrington, 2000).

Problem solving competency has emerged as a powerful platform 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, development of the problem solving competency will lead to the integration of scientific knowledge, problem solving ability, skill and experience of the students in problem-solving explanation, decision making, performances and products in their future career undertaking. However, teachers are still facing some difficulties to enhance problem solving competency of students to solve the open-ended problems in the Chemistry learning process and real world situation. By engaging the students with authentic learning practice, problem solving competency is crucial to search solutions for the open-ended problems efficiently (Lombardi and Oblinger, 2007).

1.2.4 Potential of Authentic Learning for Chemistry Problem-Solving Competency

Conventional teaching and learning style is a common condition which has a considerable impact on the delivery of knowledge and skills rather than creating an active, authentic, meaningful and innovative learning approach (Jaber and Bou Jaude, 2012). Authentic learning practice is an approach with different paradigm than conventional teaching methods. In the conventional classroom, students take a passive role in the learning process (Herrington and Herrington, 2008; Herrington and Oliver, 2000; Lombardi and Oblinger, 2007). Conventional class setting is more

to teacher-centred to deliver the knowledge to the student and apply the knowledge to answer questions in the examination. However, students would be inspired and motivated to learn new concept and skill as the better preparation to succeed in college, careers, and adulthood if what they are learning mirrors real-life contexts, equips them with practical and useful skills, and addresses topics that are relevant and applicable to their lives outside of school (Pagliaro, 2012).

An authentic learning, on the other hand, takes a constructive approach, in which learning is an active process. Teachers provide opportunities for students to construct their own knowledge through self-directed inquiry engaging, problem solving, critical thinking, and reflections in real-world contexts. This knowledge construction is heavily influenced by the students' prior knowledge and experiences, as well as by the characteristics that shape the learning environment such as values, expectations, rewards, and sanctions. Students no longer simply learn rote facts in abstract and artificial situations, but they experience and apply information in ways that are grounded in reality (Newman et al., 1995).

Due to the connectivity of students prior knowledge, experience and real life, the authentic learning has a potential to be practiced in order to overcome our greatest short coming in education to implement multisensory activities to enhance problem-solving competency in Chemistry (Evi Suryawati, 2010; Froyd, 2003; Heller et al., 1992; Ngu et al., 2006). The authentic learning approach can improve problem-solving skills among students with moderate and high cognitive skills (Evi Suryawati, 2010)). In our interpretation of contexts, authentic Chemistry practices are used for the design of meaningful learning environments to enhance the problem solving skills among students (Bulte et al., 2005; Bulte et al., 2006; Lombardi, 2007; Prins et al., 2008, Westbroek, 2005).

Due to the suggested elements and elaborated approach, a deeper analysis and structured actions are required to improve the Chemistry problem-solving competency among students (Malaysian Ministry of Education, 2012). The lack of connectedness of Chemistry with the real world and the lives of the students is a common criticism (Gabel, 1998) that has been found and reinforced in the traditional Chemistry content and teaching approaches that are resilient to change. It is expected

that the authentic learning will help promoting a better interest and understanding in scientific knowledge and competency. Therefore, by considering the prior knowledge of students and connectedness with real-world activities to solve open-ended problems, problem solving competency will be developed in learning Chemistry. This scientific knowledge competency and authentic learning practice can be incorporated with a model of problem-solving instruction in order to develop an effective and meaningful ways in learning Chemistry.

1.2.5 Model of Problem-Solving Instruction

One major issue in developing problem-solving competency among school students is a lack of problem solving skills. Researchers have already drawn attention to the issue by developed Model of Problem-Solving Instruction (Bransford and Steins, 1984; Osborn, 1963; Pizzini, 1987). The possibility to improve the students' problem-solving competency after treatment by using authentic practice or Problem Solving Instruction depends on students' scientific knowledge, problem solving skills and ability. Teachers should rationalise when selecting and deciding an appropriate problem solving model of instruction to equip students for real-world problem solving.

The problem-solving process is much more important than obtaining the ultimate answer or solution. Some scholars refined this process by calling for dividing standard questions into sub-questions. Therefore to meet the expectation of this new era of education perspective, it is essential to develop model of Chemistry problem-solving competency to enhance performance among students to solve open-ended problem especially in Chemistry. Unfortunately, the existing models of problem-solving are only focusing on the skills and metacognitive process in solving the problems without considering the problem solvers' knowledge and scientific competency, reflective, collaborative and real-world relevancy. Recently, global successes of students in problem-solving are influenced by their scientific knowledge and competency to solve open-ended problems.

Chemistry in school has traditionally been taught around open-ended problems without fostering any the problem-solving competency. In the current scenario, students learn to solve the open-ended problem as the essay question in order to score well in the examination and not for the purpose to solve problem in real life context. In other words, students are unfamiliar with open-ended problems which are non-routine, ill-defined and related with real-life situation. Hence, the ability to solve open-ended problem type in school will become a great experience and a tool to generate more number of competent problem solvers in real a world context.

Open-ended problem is commonly characterised by lacking some required information, and not necessarily having a known correct or the best solution (Nickerson, 1994; Roberts, 1995). Even when we are looking deeply into the crucial development of problem-solving in education at present, there is a lack of scientific knowledge competency base to integrate Authentic Learning Model with problem-solving instruction model to enhance problem solving competency at school level.

Up to now, far too little attention has been paid to develop a problem solving competency instructional module specifically to solve open-ended Chemistry problem for school student. This adequate instructional module of problem solving competency will assist to enhance students' performance, unlimited not only to problem solving in the subject nature but also the real world problem successfully. Therefore, to meet the expectation of this new era of education, educators and researchers need to put their efforts to design and develop a comprehensive instructional and learning module to provide more authentic learning environment by engaging students with problem solving activity or tasks. Hence, this approach is able to nurture a large number of competent future leaders as successful problem solvers for real world problems instead of only getting a good academic performance from formal education.

1.3 Problem Statement

Despite hundreds of studies over a quarter of a century have investigated to understand the difficulty of problem solving and find out the method to make it simpler, previous studies in science education have revealed that most of school and university students performed poorly in conceptual and open-ended questions in Chemistry problem solving ability (Bodner, 1991; Boži and Tramullas, 2014; Gabel and Bunce, 1991; Gayon, 2008; Nakhleh, 1993; Nakhleh and Mitchell, 1993; Osborne and Cosgrove, 1983; Surif et al., 2012, 2014). Most of studies have focused the investigation on the Chemistry problem solving ability. In addition, few studies were related to learning competency in Chemistry but not the Chemistry problem solving competency. So far, very little attention has been paid to develop problem solving competency for open-ended problems in learning Chemistry.

Most studies on problem solving have focused on improving the problem solving skills by applying a meaningful and effective instructional strategy (Evi Suryawati, 2010; Froyd, 2003; Gayon, 2008; Howe and Warren, 1989; Heller et al., 1992; Kauchak and Eggen, 1998; Reid and Yang, 2002; Surif et al., 2012). The studies have investigated the problem solving with different pedagogical approaches such as contextual or problem based learning. However, research on construction of scientific knowledge competency and authentic learning practice to promote Chemistry problem solving competency has yet to be done.

At present, there is a shortcoming of a scientific knowledge base to carry out the teaching and learning processes using authentic practice as a context for problem solving in Chemistry. Therefore, an extensive research is essential to identify the potential factors and enhance problem solving competency among school students. A learning module was developed in order to apply an appropriate strategy by intergrating Problem solving Instruction Model, authentic learning practice, constructivist learning approach and PISA Science Framework. This module acts as a tool to assist the students to apply authentic learning practice in enhancing the development of problem solving competency yo solve open-ended problems.

To fill up the gap, this research aimed to enhance the development of problem solving competency. The assessment was conducted to measure problem solving ability in solving open-ended problems. It is important to study the process of how students build their own Chemistry problem solving competency in authentic learning practice to solve open-ended problems. Potential factors to enhance the development of problem solving competency were identified and integrated with authentic learning practice in designing the module. Once the students have engaged with problem solving competency, then they are competent to solve problem in school or real life as their performance in problem solving ability has been improved. Hence, this module assisted the students to construct scientific knowledge and become competent to solve problems in learning Chemistry. Outcome from this study will generate global citizens equipped with problem solving competency (OECD, 2013).

1.4 Research Objectives

This research aimed to achieve the following objectives:

1. To determine the level of Chemistry problem solving ability and skills among school students.

2. To investigate the process and underlying factors to solve open-ended problems in Chemistry.

3. To design a Module of Authentic Chemistry Problem Solving Competency (MAC-PSC) that has potentials to enhance students' problem solving competency in solving open-ended problem in Chemistry.

4. To evaluate the students' Chemistry problem solving ability to solve the open-ended problems after implementation of Module of Authentic Chemistry Problem Solving Competency (MAC-PSC).

5. To study on how students develop their chemistry problem solving competency in authentic learning practice to solve open-ended problems in real life tasks

1.5 Research Question

The research questions addressed in this research were:

1. What is the level of Chemistry problem-solving ability and skills among school students?

2. How are the process and underlying factors to solve open-ended problems in learning Chemistry?

3. What is the students' performance in Chemistry problem solving ability to solve the open-ended problems after implementation of Module of Authentic Chemistry Problem Solving Competency (MAC-PSC).

4. How do students develop their chemistry problem solving competency in authentic learning practice to solve open-ended problems in real life tasks?

1.6 Research Theoretical Framework

The theoretical framework of this study is presented in Figure 1.1. The theoretical framework of this research incorporated a few core components from various perspectives based on Constructivist Learning Theory. This theoretical framework incorporated Problem Solving Instruction Model (Pizzini, 1987, 1996), Authentic Learning Model (Herrington, 2000), Needham's Five Phase Constructivist Model (Needham, 1987) and PISA Science Framework (OECD, 2012) to blend the appropriate domains in order to enhance students' problem-solving competency of open-ended problem in Chemistry

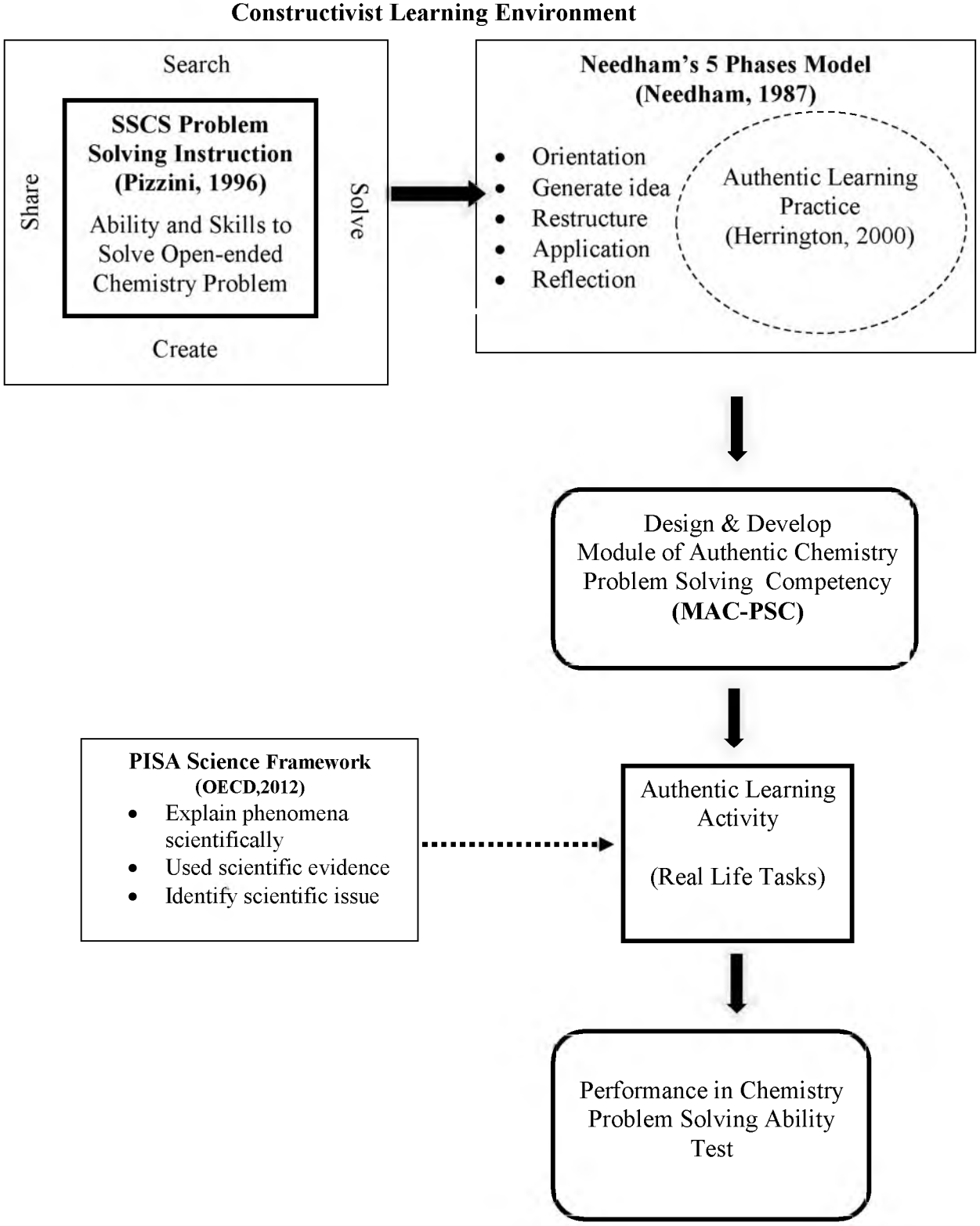

Figure 1.1 : Theoretical Framework of the research

In Figure 1.1, Problem Solving Instruction Model was used to study the ability and skills how school students solve the open-ended problem in Chemistry. The scientific knowledge competency was blended to study how students apply the problem solving skills to solve the real life tasks, provided in the developed module. The synergy input of scientific knowledge from students and application of problem solving skill with authentic learning approach have potential to enhance students' problem solving competency in Chemistry.

1.6.1 Problem Solving Instruction Model (SSCS Model)

Problem Solving Instruction Model - Search, Solve, Create and Share (SSCS Model) was selected as a problem-solving approach in the theoretical framework. This model was developed by Pizzini in 1987 for science subject and further work of implementation was done to refine the model. The SSCS model consists of four phases; search, solve, create and share. The advantage design of SSCS Model is due to cyclical steps that allow for re-entry into the various phases of the model during problem solving process as illustrated in Figure 1.2.

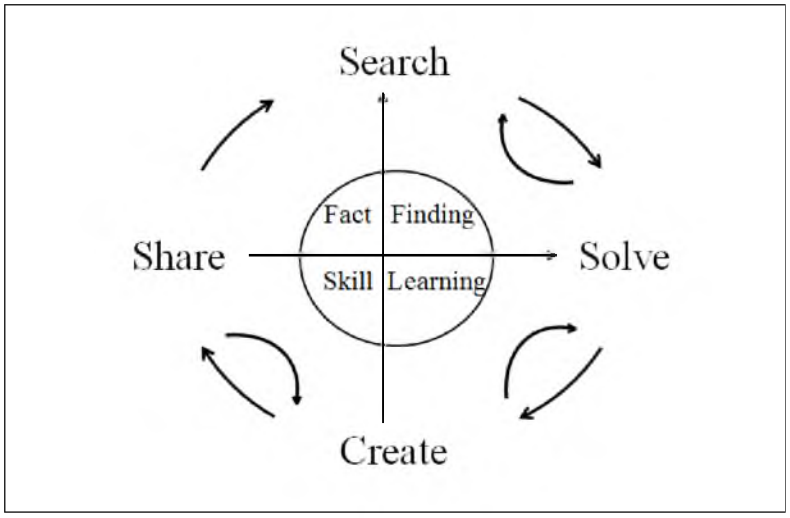

Figure 1.2 : The SSCS problem solving Instruction model (Pizzini, 1987; 1996)

Referring to Figure 1.2, learning activity in the model SSCS (Pizzini, 1991) began with the provision of problems or conditions related to the problems to be solved. Then students searched information to comprehend situations or problems presented. When the students knew or understood the problems, this led them to plan how to solve the problem using the appropriate strategy and relevant concept in Chemistry. Students created the solution based on the information and plans that have been prepared. Final phase, students shared the solution with teachers, friends and experts by conducting a discussion, forum and presentation. This sharing session gave opportunity to the students to share knowledge, ideas and justify their solution of the problem given. These problem solving skills must be mastered by students to develop the problem solving competency in learning Chemistry.

1.6.2 Authentic Learning Model

Authentic Learning Model (Herrington, 2000) emphasizes on authentic practice to engage all the senses, allowing students to experience a meaningful learning process, create a solution of the given problems and share the outcomes as mentioned in SSCS Model. For the purpose of this research, four core elements were selected as manipulated variables due to appropriateness and most relevant domains required to design the module and develop the model. Those four pertinent elements were real life activity or task, ill-defined problem, collaborative and reflective writing practices.

Real life task consists of learning activity and ill-defined problems that provide the students with opportunities to connect with the real world (Prins et al., 2008). Learning activity was designed to engage students with real life context, for example; utilized carbonated drink or lemon juice as the substance to investigate whether it was an electrolyte or non-electrolyte. It is depending on the style of learning that in the end encourages students to create a tangible, useful product to be shared with their world. Students are encouraged to solve the real life task based on the conceptual understanding and experience gained as the product of learning.

Moreover, this approach is appropriate to enhance students' problem solving competency because authentic instruction standards emphasize on higher order thinking, depth of knowledge and connectedness to the world beyond the classroom (Newman and Wehlage, 1993). Reportedly, most students were motivated by solving real-world problems during the learning process since it was related with life experience and prior knowledge (Lombardi and Oblinger, 2007).

Students are able to develop a deep understanding on what they have learned when they engage with learning activities and problems, related with real life situations (Newman and Wehlage, 1993). These activities acquire students to apply their higher-order thinking especially to solve ill-defined problem (Li et al., 2013). This ill-defined problem is presented in the form of open-ended problem with non-routine challenge that normally related with the real life situations.

Solve the problem collaboratively as one of element in authentic learning can be implemented face-to-face or with e-learning system (MOODLE). Success in learning is not achievable by an individual student working alone (Lombardi and Oblinger, 2007). Working in teams to solve the problems can promote students to communicate, interpret, relate and justify their solution. Authentic activities enable students to engage in meaningful discussions on issues presented on their learning in order to make choices, justify, make decision and reflect both individually and as a team.

In authentic learning environments, there are a few opportunities to reflect based on pre-determined learning outcomes and content that needs to be learned. In order to promote reflection, authentic and meaningful activities can be provided to enable students to practice self-assessment and share opinions with others. Reflection writing practice may engage students with learning process and optimize reflective thinking to enhance their understanding as a root to construct new scientific knowledge at the end of the lesson. Scientific knowledge competency is a major pre-requisite to be successful in problem solving especially for open-ended problems.

1.6.3 PISA 2012 Science Framework

In this framework, competency is more than just knowledge and skills. When discussing the cognitive dimensions of the specific scientific competencies, as is pertinent to the PISA, science assessment in the current cycle, reference is made to the relevant scientific knowledge and skills demonstrated by students. Scientific knowledge in PISA is used to measure the level of understanding and application of the advance scientific knowledge.

PISA is concerned with both the cognitive and affective aspects of students' competencies in science. The cognitive aspects include students' knowledge and their capacity to use this knowledge effectively to solve the problems. Current thinking about the desired outcomes of science education emphasises scientific knowledge. This outcome requires an understanding of important key concepts, explanations of science and application to solve real life problem.

In assessing scientific competencies, PISA is concerned with issues to which scientific knowledge can contribute and which will involve students, either now or in the future, in making decisions. PISA has highlighted three domains of scientific competencies that consist of (i) identifying the scientific issue (ii) explaining phenomenon scientifically and (iii) using the scientific evidence. Application of these scientific competencies is important to develop problem solving competency among school students. From the point of view of their scientific competencies, students respond to such issues (problem) in terms of their understanding of relevant scientific knowledge, ability to access and evaluate information, interpret evidence bearing on the issue and identify the scientific aspects of the issue (Koballa et al., 1997; Law, 2002).

1.6.4 Needham's Five Phase Constructivist Model

In this research, the development of problem solving competency was depending much on construction of the scientific knowledge based on students' prior knowledge and experience. Educator required identifying an appropriate learning theory to suit with learning approach to enhance this problem solving competency. Needham's Five Phase Constructivist Model is one of the established models, has been used widely in education research to enforce the construction of knowledge in various subjects at all levels, from primary until tertiary education. Every phase in this Needham's model engages students with cognitive process based on the stimulus or learning activity used to achieve the aim of respective phase.

The first phase; orientation is important to get attention and interest of students and motivate students for their continued interest in the teaching process. Orientation aims to prepare students' state of mind to proceed with the learning activity. Secondly, in phase of generating ideas; teachers identify students' alternative thinking and encourage them to think the reason they are not consistent with the idea of scientific ideas. Teacher may pose more questions to encourage thinking process among students. Third phase is dealing with restructuring ideas based on the information and activities to establish students' new concept according to their intelligence. Students will be able to make the definitions, explain concepts, question the justification and request further explanations.

The next phase will give an opportunity for students to apply idea. Phase of idea application is used to identify newly renovated or constructed in a restructuring phase to apply the idea of the new situation. The concept is built on associate and developed in other fields or in the real world. This phase is significant with authentic learning practice since the students engage with real life task to connect with real world context. The fifth phase; reflection is also synonym with reflective thinking in Authentic Learning Model. Reflection phase assesses and evaluates students' understanding of the previous ideas have changed. Reflection grid is used for the students as they question what they think, what evidence they have or what they

know about problem solving. This is a practical and effective self-assessment method to assess whether the students understand and apply what they have learned.

Those five phases in Needham's are general and practical to design a constructive learning environment but this model needs to be blended with from other models and frameworks. Needham's theory is used to provide a systematic learning flow based on students' prior experience until they are able to construct a new knowledge. Therefore, learning practice can support the specific collaborative learning activities such as solving a real life task that consists of ill-defined problems. Moreover, application of problem solving skills in SSCS Problem Solving Instruction Model will guide the students to master to solve those ill-defined problems that are also known as open-ended problems. SSCS model will attach the students with the appropriate problem solving skills (search, solve, create and share) since all these skills are lack in school curriculum. Students should be exposed with a proper problem solving strategy and given an opportunity to share the solution obtained with others. PISA Science Framework is used to evaluate the learning outcomes such as construction of scientific knowledge competency to solve the open-ended problems because Needham's model does not have a specific method or rubric for assessment. This PISA Science Framework provides three domains to measure the development of scientific knowledge competency that leads the students to solve the real life tasks given.

Integration of Authentic Learning Model Herrington (2000), Needham's Five Phase Constructivist Model (Needham, 1987), SSCS Problem Solving Instruction Model (Pizzini, 1987, 1996), and PISA Science Framework (OECD, 2012) were applied to design a comprehensive learning module of authentic Chemistry problem solving competency (MAC-PSC) to enhance the students' performance to solve open ended problems in learning Chemistry. Thence, this research has drawn the meaningful and effective module to enhance students' performance to solve open-ended problems in learning Chemistry.

1.7 Research Conceptual Framework

This research was conducted according to the research framework illustrated in Figure 1.3. Initially, the level of problem solving ability and skills among school students were determined. Problem solving skills referred to the four stages (Search, Solve, Create and Share) in Problem Solving Instruction Model by Pizzini (1987, 1996). Process practiced in solving open ended problem and factors that influenced problem solving ability of some participants were investigated. Prior analysis has explained that problem solving ability in learning Chemistry depended heavily on the conceptual understanding of the students' scientific knowledge, problem solving skills, familiarity and work collaboratively to solve open-ended problems (Suraiya et al., 2015).

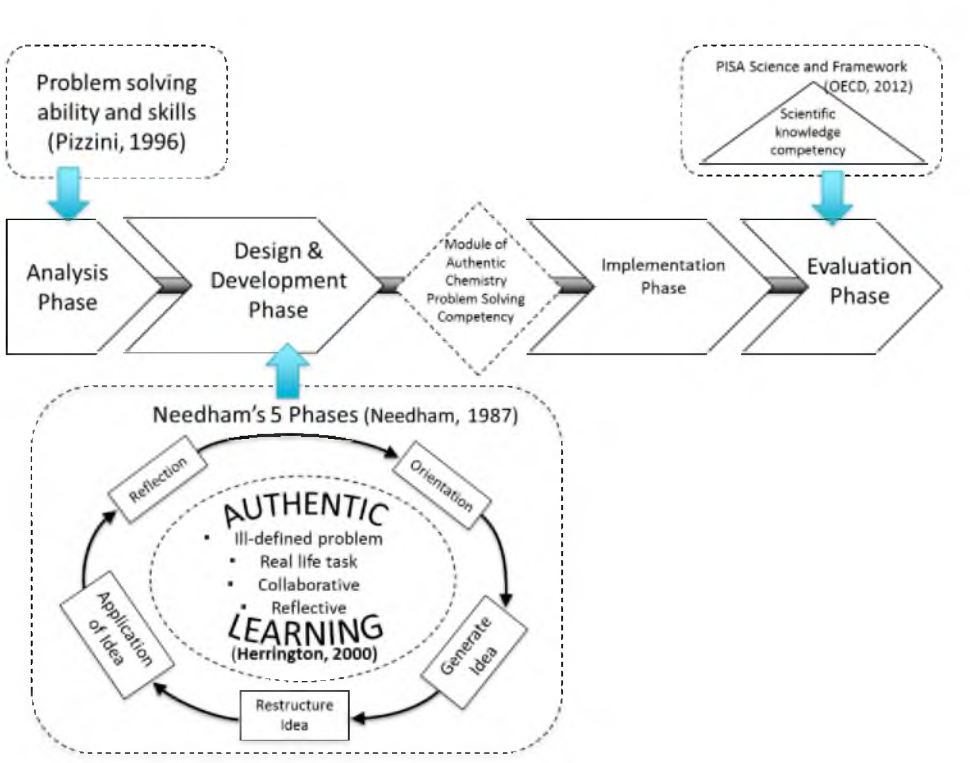

Figure 1.3: Research conceptual framework

Consequently, Needham's Five Phase model and Authentic Learning Model are considered in designing and developing Module of Authentic Chemistry Problem Solving Competency (MAC-PSC) in order to construct a deep scientific knowledge competency supported by authentic learning practice. Thus, this learning module was

designed for the purpose of promoting the development of problem solving competency in Chemistry using ADDIE Model (Rossett, 1987).

In the implementation phase, the developed learning module was used by students to learn the Chemistry topic in the authentic environment. This authentic learning environment has provided real life activities or tasks, for example using common substances in our daily life such as carbonated drinks to conduct experiment. From this approach, the research expected to investigate the students' performance in learning Chemistry and problem solving competency development in this topic. Instead of that, upon the implementation of the learning module, the students' problem solving competency development has been investigated deeply and the students' reflection grid was obtained.

Problem solving competency can be developed if students were able to apply the scientific knowledge competency to solve the open-ended problem (ill-defined and non-routine) in the authentic learning environment. Moreover, e-learning system has also been used to accomplish the problems or tasks given in the module. This approach equips the student with the problem solving competency and they apply it to confront with real-life problems outside the classroom.

Finally, the effect of the learning module on enhancing the students' development of the Chemistry problem solving competency to solve open-ended problem was investigated in the evaluation phase. Furthermore, the data in the students' Chemistry problem solving ability and problem solving competency have supported the contribution of Module of Authentic Chemistry Problem Solving Competency (MAC-PSC) as an effective learning module to enhance problem solving competency in learning Chemistry.

1.8 Research Rationale

The Ministry of Education in Malaysia has implemented appropriate efforts and steps to produce good thinkers among young generation (Malaysia Blue Print,

2012). In order to produce universal citizens as future competent in problem solvers, our present education must equip students with higher order thinking skills and noble values. As citizens in the information age, "Gen Y" must have strong problem solving and thinking skills (Morgan, 1996). Hence, knowledge and experiences can encourage and improve students' problem solving competency as an essential element in 21st century education transformation. High competency in problem solving is required to enhance the students' performance in the national and international assessment of the science subjects such as Chemistry. High performance in Chemistry will enable students to be good thinkers in problem solving in the future (Lartson, 2013).

Chemistry is one of the elective science subjects taken by form four to form six Malaysia students in secondary schools. Since Chemistry is an abstract subject, it is a challenge for teachers to ensure the students manage to grasp the knowledge and skills in constructing a strong conceptual understanding. Students are able to solve Chemistry problem such as open-ended problem well if they have a strong conceptual understanding as a prior specific knowledge in a successful problem solving.

The attention to problem competency is explicit with extensive research in this field. An approach to learning that has students solving on realistic problems to gain new knowledge and skills in context, rather than listening to lecture and memorizing vast amounts of information to be applied during assessment especially in test or examination. Authentic practice enables the students to create a meaningful learning when they are engaged with real-life situations including in problem solving. Hence, students need to be engaged with learning practice that provides more opportunity to relate the scientific knowledge with real life experiences and construct authentic problem solving competency.

For the reasons discussed above, this research aimed to design learning module to assist students to engage with authentic learning practice. This module acts as a tool to enrich the learning resources in order to enhance the development of problem solving competency in learning Chemistry. This module incorporates four

components consist of Authentic Learning Model (Herrington, 2000) as learning strategy, Problem Solving Instruction Model (Pizzini, 1987, 1996) to engage students with problem solving skills, Needham's Five Phase Model (Needham, 1987) to construct scientific knowledge and PISA Science Framework (OECD, 2012) to assess the development authentic Chemistry problem solving competency. This module facilitates the students to engage in solving open-ended problems in Chemistry generally.

This comprehensive study was conducted in this research to evaluate the Chemistry problem solving ability after the implementation of Module of Authentic Chemistry Problem Solving Competency (MAC-PSC) in enhancing problem-solving competency among school students. Besides, the researcher expected this research would contribute to learning resource development based on constructivist learning, emphasize on authentic learning practice in learning Chemistry.

1.9 Significance of the Study

This study developed a substantive model pertaining to develop problem solving competency. The model can promote the understanding of the authentic learning practice to catalyse problem solving competency among school students in learning Chemistry. This study was significant because no model or theory was found in existing literature related to the interaction among pertinent element in teaching problem solving skills and the ability of using authentic approach. More important, this study was very beneficial to some of the parties and may be expressed as follows:

1.9.1 Curriculum Development Centre, Malaysian Ministry of Education

Curriculum Development Centre, Ministry of Education in Malaysia is responsible to ensure all current educational needs in schools, especially those related to curriculum get urgent attention. Realistic measures should be implemented to enhance the development of curriculum in the education system. In this respect it was hoped that the results of this study could be used as a guide for determining the policies, curriculum, methods and approaches that improving the subject content. Most probably, it is essential to prepare more open ended problems to be solved in the text books. Findings from this study could identify the appropriate assessment to measure students' problem solving competency more efficient at the school based assessment. Outcomes of this study could also lead the ministry to prepare more modules to assist teachers especially pre service teachers to develop problem solving competency in Chemistry when they are attached or posted to schools. Moreover, this study would increase the learning resources and kits that engage the problem solving to catalyse its implementation in school especially to the schools in rural areas.

1.9.2 The global principals

The principals are the person ultimately responsible for ensuring that each school's goal and mission are accomplished properly. Therefore, this study helped them to identify the weaknesses that existed, especially in terms of problem solving competency of students in the classroom and tried to take some steps to increase the level of students' achievement in Chemistry or science subjects at schools. Principals can initiate the authentic learning environment to offer a meaningful learning practice.

1.9.3 The teachers in school

There is no doubt that teachers are the most directly involved with the process of teaching and learning in the classroom. Teachers should benefit more as a result of this study and to make it as a guide to reach and inspire students to continue to learn effectively and master the knowledge and skills that are important before they can face the global challenge. Results from this study would help teachers to identify students' competencies of problem solving that may affect their academic achievement. In addition, problem solving competency has become a core criteria to perform well and systematically in their career undertaking.

1.9.4 The secondary school students

Modules developed from this research were beneficial in assisting students to become competent problem solvers in Chemistry. Most students have such difficulties in solving problems open-ended problems in Chemistry. This study identified the underlying factors that influenced the students' competency in solving Chemistry problems especially open-ended problems and authentic learning was proposed as an effective and meaningful approach to develop the problem solving competency.

1.10 Research Scope and Limitation

This research aimed to develop a Chemistry problem solving model and learning module that incorporated the authentic practice and scientific knowledge competencies to provide an authentic learning environment by engaging the students with problem-solving competency in solving open-ended problems.

The research involved a few of full boarding schools in Malaysia. Therefore this research could only be generalized to high achieving students from boarding schools in Malaysia. Students selected as the participants were considered as scholar students homogenous of science education background. Research only focused on

students' problem solving competency in Science generally and specifically in Chemistry. This research was limited to determine the problem solving competency of open-ended Chemistry problems. Scientific knowledge competency was investigated from the real life tasks.

However, the findings of this research would help the relevant authorities, especially teachers, school administrators and officers from the Malaysia Ministry of Education in order to enhance Chemistry problem-solving competency. In addition, this research aimed to enhance problem solving competency at present and continuously moving towards 21st century education.

1.11 Operational Definition

There were some terminologies frequently used in this research, which were:

1.11.1 Problem-Solving Competency

By the definition, "competency" is a combination of knowledge, skill and attitude. Knowledge is an awareness of a material you get through the use of experience, books or any other media. Skill is the ability to execute a certain task. Attitude demonstrates a person's willingness. The PISA 2012 definition of problem-solving competency is grounded in these generally-accepted meanings of "problem" and "problem solving." Problem-solving competency is defined as an individual's capacity to engage in cognitive processing to understand and resolve problem situations where a method of solution is not immediately obvious (OECD, 2012). It includes the willingness to engage with such situations in order to achieve one's potential as a constructive and reflective citizen.

In this study, problem solving competency was a capability to apply scientific knowledge and problem-solving skills to solve open-ended Chemistry problem based on students' actual performance.

1.11.2 Authentic Learning Practice

According to Lombardi and Oblinger (2007), authentic learning typically focused on real life, complex problems and their solutions, using role-playing exercises, problem-based activities, case studies, and participation in virtual communities of practice. Learning-by-doing was generally considered the most effective way to learn. The internet and a variety of emerging communication, visualization, and stimulation technologies now make it possible to offer students authentic learning experiences ranging from experimentation to real-world problem solving.

In this study, authentic learning practice was implemented only with four core elements; real-world relevance, ill-defined problem, collaborative problem-solving and reflective assessment. The authentic learning practice was created by providing real life activities and tasks to solve the open ended problems collaboratively with a reflective assessment and supported by e-learning module (MOODLE) as a tool.

1.11.3 Open-Ended Problems

The new-style open-ended problem can be used to assess whether or not a student has truly grasped a Chemistry concept (Scottish Qualification Assurance, 2012). The student is required to draw deep understanding of key Chemistry principles in order to solve an open-ended problem. The open-ended nature of these questions is such that there is no unique correct answer. The less prescriptive marking instructions focus on rewarding students for their understanding of Chemistry.

In this study, open-ended problem was an ill-defined and a non-routine problem with real-life context. Open-ended problems were presented in Chemistry Problem Solving Ability Test sheet and real life task in the developed module (MAC-PSC). This open-ended problem can be solved using students' scientific knowledge competency and learning experience gain in life. All open-ended

problems may have more than one possible solution. Different students may write totally different responses depended on the problem solving competency. However, as long as these responses meet the assessment criteria then marks were awarded.

1.11.4 Problem Solving Skills

Problem solving skills involves a process of working in details of a problem to reach a solution. Problem solving skills indicate the steps including the strategy applied to solve a problem (Mayer, 2013). Pizzini (1987) introduced four steps in to solve problems in learning Science. In this study, the cyclic four steps (SSCS) are applied by the students to solve the open-ended problems in the pre and post Chemistry Problem Solving Ability Test (CPSAT) and real life task during the intervention. The four cyclic steps consist of searching the information from the given problem (SEARCH), solving the problem by using the relevant concept or formula or strategy (SOLVE), creating the solution that adequate to the real life situation(CREATE) and the last step is sharing the solution with scholar group in order to justify it as a correct and accepted one(SHARE).

1.11.5 Problem Solving Ability

Problem solving ability shows capability of individual to apply prior knowledge and skills to accomplish the problem task (Reid & Yang, 2002). In this study, problem solving ability refers to performance showed by the students to solve an open-ended problem until they reach the solution in a certain duration given. Problem solving ability consists of three main components which are; 1) ability to understand the problem; 2) ability to connect the related concepts; and 3) ability to solve the problem and finally find correct or acceptable solution.

1.11.6 Authentic Chemistry Problem Solving Competency

By integrating the authentic learning practice to enhance problem solving competency for Chemistry open-ended problem, researcher has introduced this new term 'Authentic Chemistry Problem Solving Competency'. Authentic Chemistry problem solving competency is a capability of an individual to solve Chemistry open-ended problems or real life task based on individual scientific knowledge, problem-solving skills and able to reach a realistic solution.

1.12 Summary

This chapter presented an overview of the background and rationale for this research. It was clear that problem-solving competency was regarded as one of the fundamental aims of Chemistry education. The difficulties faced by secondary school students in Chemistry problem-solving has been highlighted but so far there has not been an effective problem-solving instruction to guide the students toward more successful problem-solving experience. Researcher has outlined some reasons and proposed a different way of looking at this issue from the perspective of student's competency in solving open-ended problem with authentic learning practice with an appropriate problem-solving instruction model and Needham's Five Phase Constructivist Model. PISA Science Framework (OEDC, 2012) was selected to expose student with domains in international education assessment. The key concepts of the research have been briefly introduced and further explanations will be provided in the next chapter drew from more studies.

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