Faculty of Resources Science and Technology

Development of a Practical Kit and a Citizen Scientist Program for Learning Chemistry

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DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Signature

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ABSTRACT

Laboratory practical is an essential component for effective learning of science. Providing laboratory experience can be challenging for some rural schools with limited laboratory facilities. The situation was exacerbated when schools were closed due to the COVID-19 pandemic. This thesis reports a laboratory kit design based on the Standard Curriculum for Secondary Schools in Malaysia (Kurikulum Standard Sekolah Menengah, KSSM). The kit was evaluated by students and experienced teachers from town and rural schools. Pre- and post-test was conducted with the students before and after using the kit. A questionnaire was disseminated to appraise the students' perceptions on practical learning. There was a significant improvement ($p < 0.05$) in the overall score of the post-test (90.32) compared to the pre-test (71.00). Both rural and town schools demonstrated a significant increase in the overall mean scores, from 68.67 and 73.34 in the pre-test to 91.34 and 89.33 in the post-test. There was also improvement in affection for chemistry among students after using the kit. The practical kit can be deployed in schools with laboratory constraints and to be used outside the school settings. It was designed to be affordable compared to traditional lab setting, safe and environmental-friendly due to minimal chemical used, and providing individualized hands-on exposure. Besides, this thesis also reports a citizen science program on household food waste for students to introduce the idea of citizen science to them and to evaluate their learning experience. The project focused on quantification of avoidable solid food wastes in the households using the food waste diary. The results were positive, that is more than 80% of the participants agreed that this program increased their interest in chemistry learning, raised awareness of food waste reduction and waste management, and improved scientific skills such as food waste measurement.

Keywords: Chemistry laboratory kit; COVID-19; Standard Based Curriculum for Secondary School; citizen scientist; food waste

Pembangunan Kit Amali dan Program Saintis Warganegara untuk Pembelajaran Kimia

ABSTRAK

Aktiviti amali adalah komponen penting untuk pembelajaran sains yang berkesan. Untuk menyediakan pengalaman makmal boleh menjadi cabaran kepada sekolah luar bandar yang mempunyai kemudahan makmal yang terhad. Keadaan bertambah serius apabila sekolah ditutup akibat pandemik COVID-19. Tesis ini melaporkan rekabentuk kit amali berasaskan Kurikulum Standard Sekolah Menengah (KSSM) di Malaysia. Kit ini dinilai oleh pelajar dan guru berpengalaman dari sekolah bandar dan luar bandar. Ujian pra dan pasca telah dijalankan bersama murid sebelum dan selepas menggunakan kit. Satu soal selidik telah diedarkan untuk menilai persepsi pelajar terhadap pembelajaran amali. Terdapat peningkatan yang ketara ($p < 0.05$) dalam markah keseluruhan pasca ujian (90.32) berbanding pra ujian (71.00). Kedua-dua sekolah luar bandar dan bandar menunjukkan peningkatan yang ketara dalam skor min keseluruhan daripada 68.67 dan 73.34 dalam pra ujian kepada 91.34 dan 89.33 dalam pasca ujian. Terdapat juga peningkatan dalam minat terhadap kimia dalam kalangan pelajar selepas menggunakan kit tersebut. Kit amali boleh digunakan di sekolah dengan kekangan makmal dan untuk digunakan di luar persekitaran sekolah. Ia direkabentuk dengan harga mampu milik berbanding dengan makmal tradisional, selamat dan mesra alam kerana penggunaan bahan kimia yang minimum, dan memberikan pendedahan individu secara langsung. Selain itu, tesis ini juga melaporkan program sains warganegara tentang sisa makanan untuk pelajar bagi memperkenalkan idea sainstis warganegara kepada mereka dan menilai pengalaman pembelajaran mereka. Projek ini memberi tumpuan kepada pengiraan sisa makanan pepejal yang boleh dielakkan dalam isi rumah menggunakan diari sisa makanan. Terdapat keputusan yang positif, iaitu lebih daripada 80% peserta bersetuju bahawa program ini meningkatkan minat mereka *dalam pembelajaran kimia, meningkatkan kesedaran tentang pengurangan pengurusan sisa makanan, dan meningkatkan kemahiran saintifik seperti pengukuran sisa makanan*.

Kata kunci: *Kit amali kimia; COVID-19; Kurikulum Berasaskan Standard Sekolah Menengah; saintis warganegara; sisa makanan*

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ASM	Academy of Science Malaysia
COVID	Coronavirus Disease
DOHE	Department of Higher Education
KBSM	Kurikulum Bersepadu Sekolah Menengah (Integrated National Curriculum for Secondary School)
KBSR	Kurikulum Standard Sekolah Menengah (Standard Secondary Schools Curriculum)
KSSM	Kurikulum Standard Sekolah Menengah (Standard Secondary Schools Curriculum)
OED	Oxford English Dictionary
PPPM	Pelan Pembangunan Pendidikan Malaysia (Malaysia Education Development Plan)
RLs	Remote Labs
RM	Ringgit Malaysia
SMK	Sekolah Menengah Kebangsaan (National Secondary School)
SPM	Sijil Pelajaran Malaysia (Malaysian Certificate of Education)
SPS	Science Process Skills
STEM	Science, Technology, Engineering and Mathematics
UNIMAS	Universiti Malaysia Sarawak
VLs	Virtual Labs

CHAPTER 1

INTRODUCTION

1.1 Study Background

Chemistry is one of the most important branches of science; it is a difficult subject for many students because curricula usually contain many abstract concepts central to further learning in chemistry and other sciences (Taber, 2002). Chemistry develops from theoretical and practice, and the heart of chemistry comes from practise at the laboratory (Hodson 2001). In learning chemistry, it is important that students use an inquiry learning pedagogical approach to obtain their thoughts, opinions, and observations. This student-centred approach strengthens the connection between teaching and research (Spronken-Smith & Walker, 2010). However, there are problems related to chemistry education worldwide in general and in Malaysia in particular. These include, first, the ability to develop practical skills, and second, the ability to apply various chemistry skills to solve problems daily (Fadzil & Saat, 2013).

The first issue, the ability to develop practical skills in students is of concern to educators. The ability to perform hands-on work in the science laboratory is a crucial science process skill and a common goal of the science standards (Schwichow et al., 2016). Hamza (2013) argued that students need hands-on work experiences for future learning and that science experiences can be fruitful in a different setting. Hands-on work gives students the opportunity to investigate phenomena, draw conclusions, and practice scientific skills using equipment, leading to meaningful science learning and the development of critical thinking skills (Shana & Abulibdeh, 2020).

Several studies shown that many students at all levels of education have misconceptions about basic chemistry concepts (Nakhleh, 1992; Garnett et al., 1995; Taber, 2002; Çalik et al., 2007). The main reason is that chemistry knowledge is learned at three levels, namely submicroscopic, macroscopic, and symbolic (Figure 1.1) and the connection between these levels should be explicitly taught (Johnstone, 1991; Gabel, 1992; Harrison & Treagust, 2000; Ebenezer, 2001; Ravialo, 2001; Treagust et al., 2003; Taber, 2003; Chandrasegaran et al., 2007).

Macroscopic level describes the quantity properties of tangible and visible phenomena in learners' everyday experiences of observing changes in the properties of matter, such as changes in colour, formation of precipitates and release of gases in chemical reactions (Chandrasegaran et al., 2009). Luviani et al. (2021) emphasized that the submicroscopic level is also known as a molecular representation that provides explanations at the atoms, molecules, and ions level and Symbolic level involves the use of chemical formulas and equations, drawings, diagrams, and models of particles to symbolize the matter (atoms, molecules and ions). It can provide information at both the macroscopic level (number of mole of the substances) and the submicroscopic level (number of formula units of the substances). The interactions and distinctions between them are also important features of chemistry learning and necessary to understand chemical concepts (Luviani et al., 2021). Thus, if students have difficulty at one of the levels, it will most likely affect their understanding at another level.

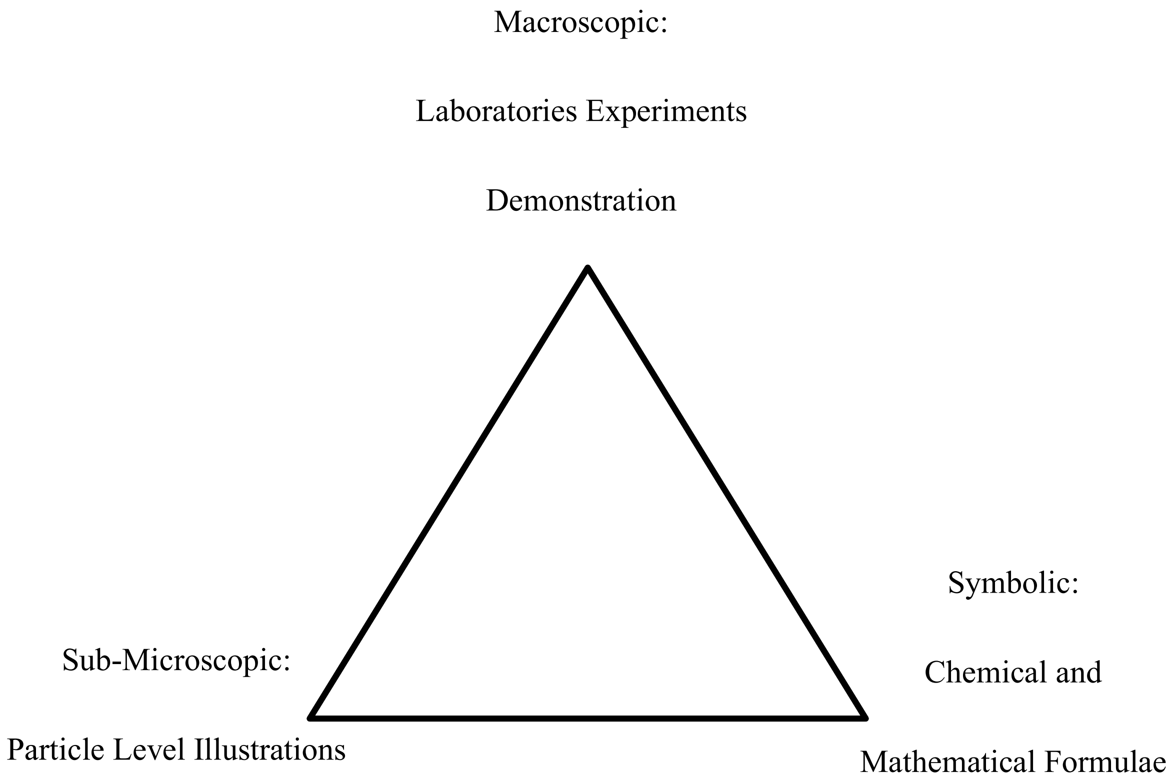

Figure 1.1: Levels of chemistry knowledge

Numerous studies have confirmed that science learning can be enhanced when students conduct hands-on experiments in the laboratory (Hofstein, 2004; Hofstein & Lunetta, 2004; Lunetta et al., 2007). Laboratory activities have been assigned a special role in science education. Therefore, hands-on laboratory work is fundamental and essential to students' understanding and skill development in science education, but it is often missing from actual school curricula around the world (Bradley et al., 1998). Laboratory activities play an important role to reinforce understanding on the concepts making chemistry real for the students. Both physical and cognitive skills can be developed through the laboratory experience, such as manipulating variables, constructing hypotheses, understanding and following procedures, making observations and inferences, taking data readings, analysing data and results (Dietmar, 2021).

Besides the ability of practical skills, it is crucial to develop the ability to apply different chemistry knowledge in daily problem solving. Several studies have shown that secondary school students prefer to actively participate in learning science through hands-on laboratory work (McFarlane, 2013; Hasni & Potvin, 2015; Schwichow et al., 2016). To enhance students' interest in learning science, project-based approach can provide opportunities for students to engage and develop an ability to apply different chemistry concepts in daily problem solving. Previous research revealed that citizen science program has a great potential to foster learning of science (Bonney et al., 2009). Citizen science is scientific research conducted completely or partially by amateur or nonprofessional scientists (Gura & Trisha, 2013). Little research has been done on the effects of citizen science projects on the knowledge and attitudes of participants, but available data suggest that the results are positive (Brossard et al., 2005). There are researches on citizen science, from a long-running and large-scale project to measure precipitation of raining, hail and snow in the United States, related to environmental chemistry (Holzer et al., 2011).

In Malaysia, enrolment of students into science stream fell short of expectations. The government has targeted 60% of student entry into science stream and 40% for the art stream (Chew et al., 2014). This challenge to improve science literacy among Malaysian students is a heated conversation in the education field. According to studies, the problem of low enrolment in science subjects at the secondary school is worrying (Smith, 2011; Fadzil & Saat, 2014; Kennedy et al., 2014). Table 1.1 shows the enrolment of students into science stream from the year 2018 to 2020 based on the record of the Ministry of Education (Laporan Tahunan Pelan Pembangunan Pendidikan Malaysia, 2020). The percentage of students in Science, Technology, Engineering and Mathematics (STEM) were 47.18 % for the year

2020, 43.47% for the year 2019 and 44.36% for the year 2018 (Laporan Tahunan Pelan Pembangunan Pendidikan Malaysia, 2020).

Table 1.1: The percentage of enrolment of students in science stream

Year	Percentage (%)
2018	44.36
2019	43.47
2020	47.18

The trends reported in Malaysia have also been observed in other countries, namely France (Charbannier & Vayssettes, 2009), England and Wales (Smith, 2011), Australia (Kennedy et al., 2014) and Western European countries (Sjøberg & Schreiner, 2005; Organisation for Economic Cooperation and Development, 2007; Van Griethuijsen et al., 2015). This suggests that the decline in enrolment of students in science education may transcend national and cultural boundaries. To make matters worse, student interest in science has gradually declined over the years (Osborne et al., 2003). This has led policymakers to worry about their country's economy, where science and technology play an essential role in their people (Gago et al., 2004). Previous research showed that the lack of practical work may affect the students' interest and reduce their enrolment in science classes (Tolessa & Seid, 2016).

The Ministry of Education of Malaysia had review on the education system in Malaysia in 2011. The outcome was the implementation of Standard Secondary School Curriculum (Kurikulum Standard Sekolah Menengah, KSSM) starting in 2017 to replace the Integrated Secondary School Curriculum (Kurikulum Bersepadu Sekolah Menengah, KBSM) which began in 1989. This step aimed to meet new policies under Malaysia Education Development Plan (Pelan Pembangunan Pendidikan Malaysia, PPPM) 2013-2025 for curriculum quality to be comparable to the international standards (Dokumen Standard Kurikulum dan Pentaksiran, 2018).

The KSSM chemistry curriculum aims to develop scientifically literate students through learning experiences, understanding chemistry-related concepts, skill development, and appreciation of the impact of scientific and technological developments in society (Curriculum Development Center, 2018). Students will be able to communicate, make decisions based on scientific knowledge, and be able to continue their education and careers in STEM (Science, Technology, Engineering, and Mathematics). The chemistry curriculum at KSSM emphasizes inquiry and problem solving. Scientific process skills and thinking skills are built in the process of inquiry and problem solving. The scientific process skills (SPS) are needed to find solutions to a problem or make decisions in a systematic way (Curriculum Development Center, 2018). The mental process promotes critical, creative, analytical, and systematic thinking. Mastery of SPS combined with a positive attitude and sound knowledge ensures effective thinking in students. Manipulative skills are psychomotor skills that enable students to perform hands-on work in science. They include the development of hand-eye coordination (Curriculum Development Center, 2018). Examples of these manipulative skills include the ability to correctly and safely handle scientific equipment, chemical substances, and specimens.

Nevertheless, there are some challenges in implementing practical chemistry sessions in Malaysia, especially with limited facilities for practical sessions in rural areas or home-based students or students learning remotely due to quarantine/pandemic Covid-19.

Campbell (2001), Fadzil and Saat (2013) have found that science teaching and learning have focused too much on the retention of knowledge, with students doing too much writing and too little hands-on work. Thus, students may have trouble in handling materials and apparatus in the laboratory. This would end up producing or graduating students who lack of the ability to develop practical skills (Campbell, 2001; Fadzil & Saat, 2013). In Malaysia, most schools are fully equipped with laboratories, however the facilities are insufficient to support individual work. Generally, schools can cater to group work in the size of 4-5 students (Sharifah & Lewin, 1993). In fact, students should work through the hands-on activities individually to promote and develop various process-related skills, such as making hypothesis and observation, interpreting data, making prediction and communication, and drawing conclusions (Organisation for Economic Co-operation and Development, 2007). According to Tesfamariam, Lykknes, and Kvittingen (2015), the obstacles to conduct hands-on activities are mainly due to large class sizes, budget and time constraints, and inadequate teacher preparation. As a result, hands-on activities are often dropped from the curriculum in most developing countries.

Some institutions have innovated practical experience through virtual or remote labs (Zakaria et al., 2012). These labs allow learning to occur regardless of location or time; they transfer instruction from the impenetrable walls of a classroom to any location where a computer is available and allow applications to be made more dynamic through simulations (Yang & Heh, 2007). However, some skills and abilities traditionally acquired in hands-on laboratories, such as using laboratory equipment and tools, measuring, and adapting real laboratory experiences to daily life, cannot be developed virtually. Besides, there is lack a of interaction between peers and teachers in virtual learning (Ma & Nickerson, 2006).

Some institution use microscale chemistry in both developed and developing countries to provide hands-on experiences in schools. Research by Hanson et al (2011) has shown that small-scale devices can provide the same function as large macro-glass devices for standard laboratories. However, there are limitations in microscale chemistry techniques; it can be challenging to handle the miniature apparatus – fitting, observing the results and cleaning. Also, microscale apparatus can be quite costly to maintain for schools (Tesfamariam et al., 2014).

Besides, there are challenges on the second issue, which is the ability to apply different concepts for problem solving in chemistry. This is confirmed by Lunetta et al (2007) stated that educators always face challenges in nurturing interest in learning chemistry among school children. Real life application is necessary for the chemistry knowledge and the scientific skills remain only theoretical science but not practical activities. Students need to recognize the chemical nature and interactions of matters in everyday substances and do not understand the role chemistry knowledge plays in solving everyday problems (Cardellini, 2012). They need to see the practical benefits of their efforts and the usefulness of the chemical knowledge they have acquired.

According to research by Cardellini (2012), apart from nurturing interest in chemistry, it is challenging to ensure that students see the importance of chemistry instruction by applying chemistry concepts to solve problems from daily life, such as food waste. Learning about the nature of chemistry, poses the problem of how to facilitate actual hands-on investigations in which chemical ideas play a central role and skills are used (Marchak et al., 2021). Citizen Science with a focus on chemistry offers a limited alternative, but one that has yet to be fully explored. Therefore, the connection between chemical theory and its real-world applications must be demonstrated to foster student interest in the subject (Lukyanenko et al., 2020).

Previous research by Dickinson and Bonney (2012) has shown that the major challenges to be overcome if the citizen scientist approach to lifelong chemical education is to be used more widely are three: increasing the willingness of professional chemists to play a leading role in projects, convincing these chemists to work in multidisciplinary teams with other scientists, since "Environmental chemistry" is expected to be a primary target, designing projects that appeal to youngsters and can be easily incorporated into their current lifestyles (Dickinson & Bonney, 2012).

1.2 Problem Statement

This research is aimed at developing a practical kit with flexibility and affordability; and designing a citizen scientist program on food waste. According to Mafumiko (2008), there was non-availability of the necessary equipment for chemistry activities, the cost of expensive, delicate and complicated equipment puts the benefits of science out of the reach of students especially those in less endowed communities in rural areas. Students may only observe demonstrations of such activities, as they are performed by teachers, or through video animations (Mafumiko, 2008). There was micro-scale chemistry equipment has been used to replace conventional macro equipment, but they were not suitable for Malaysian syllabus and curriculum. For examples, micro chemistry equipment was introduced in underprivileged basic schools in South Africa by Bradley (2000), Tanzania by Mafumiko (2008) and Mozambique by Kombo (2006). In this study, the practical kit was developed for KSSM syllabus to ensure the ability of practical skills among students at an individual level. It is flexible and easy to carry, whether used in schools with laboratory constraints or outside the school settings.

To nurture the ability of applying chemistry knowledge in daily life, citizen scientist program on food waste was introduced in this research. This is to expose the students to learn through citizen science where this strategy can be potentially integrated into chemistry curriculum in order to boost the interest of students in learning chemistry (Jenkins, 2011). .

1.3 Objectives

In order to improve the teaching and learning of secondary students in chemistry, this study attempted to improve the practical experience and investigate the potential active learning programme for these students. The specific objectives of the study include:

(i) To develop a chemistry portable practical kit that contains experiments for upper secondary chemistry students that serve the KSSM.

(ii) To develop an inquiry learning program on the food waste topic under KSSM chemistry syllabus based on the citizen scientist approach .

1.4 Significance of the Study

In the context of education for all, we must take up the challenge of providing hands-on experience in chemistry (Bradley, 1999). The success of this research study can have a significant impact on chemistry education in Malaysia. First, the practical set developed can reduce the cost and minimise the chemical waste disposal. Chemistry experiments can even be conducted in rural schools or at home without having traditional laboratory setting (Mashita, 2009). Secondly, students can read and understand the procedure in the user's