Small Scale Approach for Teaching and Learning Chemistry in Malaysia

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Abstract

Chemistry is an experimental science and its development and application demand a high standard of experimental work. Experiments are considered a subset of practical or laboratory work which is a didactic method of learning and practicing all the activities involved in Chemistry. The laboratory work also has great potential in promoting positive attitudes and providing students with opportunities to develop skills regarding cooperation and communication. Central to the teaching-learning approach in the chemistry curriculum is the mastery of scientific skills, which comprise process skills, manipulative skills and thinking skills. Students require the hands-on practical and personal laboratory experiences to acquire the skills. The Malaysian chemistry Form Four syllabus comprises nine topics with fifty experiments and the Form Five syllabus comprises five topics with thirty five experiments. Introducing the small scale approach in chemistry practical work would help overcome problems associated with the practical activities since this technique allows the students to conduct experiments individually. It is an environmentally safe technique with a pollution-prevention approach accomplished by using miniature glassware and significantly reduced amounts of chemicals. This paper reported the feasibility of using the small scale approach in Malaysian chemistry syllabus. The feedback from teachers and students towards this approach also reported.

Keywords: Small scale approach, Teaching and learning chemistry

Introduction

In Malaysian educational system, chemistry is offered to students at the upper secondary level beginning in Form Four (equivalent to Grade 10, in the US system). Students who have followed the chemistry curriculum will have a basic foundation in chemistry to enable them to pursue formal and informal further education in science and technology.

Part and parcel of learning chemistry is carrying out laboratory practicals. From an educational point of view, chemistry without laboratory work is seen as a body of factual information and general laws which conveyed nothing of lasting power to the mind (Layton, 1990). Central to the teaching-learning approach in the chemistry curriculum is practical work geared towards the mastery of scientific skills, which comprise process skills, manipulative skills and thinking skills.

Practical work in chemistry gives students opportunities to gain these skills through scientific investigations and hands-on activities and has the potential to significantly enhance learning and development of conceptual understanding. It may offer a unique learning environment that can help students construct their knowledge, develop logical and inquiry-type skills and develop psychomotor skills. It can also promote positive attitudes and provide students with opportunities to develop skills regarding cooperation and communication (Hofstein, 2004).

Small Scale Chemistry

Small scale chemistry is an alternative approach to overcome some of the problems associated with practical work, since it provides hands-on activities and personal experiences for students using reduced amounts of chemicals, miniature labware, safe, easy manipulative techniques and high quality skills. Precision or accuracy of experiments is not compromised and teachers can also use it as a tool to design new laboratory acitivities (Cooper *et al*., 1995, Bradley, 1999, Singh *et al.*, 1999, Tallmadge *et al.*, 2004).

This laboratory-based approach can improve students skills in handling equipment, encourage them to do experiments, and also stimulate them to do experiments carefully and patiently. Kelkar and Dhavale (2000) reported that undergraduate students performed experiments with more care and their skills in handling the equipment were markedly improved after adoption of this technique in their laboratory.

Among the benefits of small scale chemistry are improved safety, cost and time savings, environment-friendliness, pollution prevention, more adaptable equipment and also enhanced chemistry learning. In particular, benefits of small scale chemistry which include the following (McGuire *et al*., 1991, National Microscale Chemistry Centre, 1993, Cooper *et al*., 1995, Bradley, 1999, Singh *et al.*, 1999, Kelkar & Dhavale, 2000, Vermaak & Bradley, 2003, Tallmadge *et al.*, 2004).

Small Scale approach for Malaysian Chemistry Syllabus

The Malaysian chemistry Form Four syllabus comprises nine topics with fifty experiments and the Form Five syllabus comprises five topics with thirty five experiments (Curriculum Development Center, 2004 & 2006). The Form Four syllabus comprises nine topics and the Form Five syllabus comprises five topics which are organized based on the following themes: Introduction to chemistry, Matter around us, Interactions between chemicals and Production and management of manufactured chemicals.

The topics for the Form Four syllabus include Introduction to chemistry, The structure of the atom, Chemical formulae and equations, Periodic table of elements, Chemical bonds, Electrochemistry, Acids and bases, Salts and Manufactured substances in industry. Topics for Form Five syllabus include rate of reaction, carbon compound, oxidation and reduction, thermochemistry and chemicals for consumers. Table 1.2 and Table 1.3 show topics and listing of the experiments in Form Four and Form Five for Malaysian chemistry syllabus. Most of the experiments involved in Form Four and Form Five are qualitative in nature.

The small scale approach was adapted in Malaysian chemistry syllabus by using The Microchemistry kit from RADMASTE centre South Africa as basic reference since it is widely used for African secondary schools and also can be used for many general chemistry experiments. This stage was conducting by doing all the experiments by traditional and small scale set-up. The set-up and chemicals used in traditional experiments is based on chemistry text book whereas for the small scale experiments developed, preliminary investigations determined the appropriate chemicals and optimized the volume and concentration for the chemicals to be used for each experiment. All the experiments were repeated at least three times as well as estimation was made in terms of quantity of chemicals used, waste produced and time duration. The qualitative experiments were repeated at least three times whereas for the quantitative experiments which involved weighing, volume estimation or calculation of concentration were repeated many times until constant values were obtained.

Table 1: List of topics and experiments in Form Four KBSM chemistry syllabus

	Topics & Experiments:	**Small scale**
1.	**Introduction of Chemistry**	
	Investigating the effect of the temperature of water on the solubility of sugar	Yes
2.	**The Structure of The Atom**	
	Diffusion of particles in solid, liquid and gas	Yes
	Determining the melting and freezing point of lauric acid, $C_{12}H_{24}O_2$	No
3.	**Chemical Formulae and Equations**	
	Determining the empirical formula of magnesium oxide	Yes
	Determining the empirical formula of copper(II) oxide	Yes
	Constructing balanced chemical equations	Yes
4.	**Periodic Table of Elements**	
	Investigating the chemical properties of lithium, sodium and potassium	No
	Investigating the chemical properties of group 17 elements	Yes
	Studying the properties of the oxides of elements in period 3	Yes
5.	**Chemical Bonds**	
	Preparation of ionic compounds	Yes
	Comparing the properties of ionic and covalent compounds	Yes
6.	**Electrochemistry**	
	Classifying chemicals into electrolytes and non-electrolytes	Yes
	Electrolysis of molten compounds	Yes
	Investigating the electrolysis of aqueous copper(II) sulphate, $CuSO_4$ solution and sodium hydroxide, NaOH solution.	Yes
	Investigating the effect of the positions of ions in the electrochemical series on the products of electrolysis.	Yes
	Investigating the effect of the concentration of ions in a solution on the	Yes

	products of electrolysis.	
	Investigating the effect of the types of electrodes on the products of electrolysis	Yes
	Purification of copper	Yes
	Electroplating of an iron nail with copper	Yes
	Production of electricity from chemical reactions in a simple voltaic cell	Yes
	Production of electricity from chemical reactions in a Daniel cell	Yes
	Constructing the electrochemical series based on the potential difference between two metals	Yes
	Constructing the electrochemical series using the principle of displacement of metals	Yes
	Confirming the predictions on the displacement reaction	Yes
7.	**Acids and Bases**	
	Investigating the role of water in showing the properties of acids	Yes
	Investigating the role of water in showing the properties of bases	Yes
	Studying the chemical properties of acids	Yes
	Studying the chemical properties of bases	Yes
	Measuring the pH of solutions used in daily life	Yes
	Measuring the pH of acidic and basic solutions with the same concentration	Yes
	Preparing 100 cm^3 of 2.0 mol dm^{-3} standard sodium hydroxide solution	No
	Preparation of a solution by dilution method	No
	Investigating the relationship between pH values with molarity of an acid and a base	Yes
	Determining the end point of the titration between hydrochloric acid, HCl and sodium hydroxide, NaOH solution using an acid-base indicator	Yes
8.	**Salts**	
	Solubility of nitrate, sulphate, carbonate and chloride salts	Yes
	Preparation of soluble salts by mixing acids with bases	Yes
	Preparation of soluble salts by mixing an acid with an insoluble metal oxide	Yes
	Preparation of a soluble salt by mixing acid with metal	Yes
	Preparation of a soluble salt by mixing acid with an insoluble metal carbonate	Yes
	Preparation of insoluble salts by carrying out a precipitation reaction	Yes
	Constructing the ionic equation for the formation of lead(II) chromate(VI)	Yes
	Studying the colour and solubility of salts in water	Yes
	Carrying out chemical tests to identify gases	Yes
	Studying the effect of heat on carbonate and nitrate salts	Yes
	Testing for the presence of anions in aqueous solutions	Yes
	Testing for the presence of cations in aqueous salt solutions	Yes
9.	**Manufactured Substances in Industry**	
	Investigating the properties of ammonia, NH_3	Yes
	Preparation of ammonium sulphate fertilizer	Yes
	Comparing the hardness of pure metal and its alloy	No
	Comparing the rate of rusting between iron, steel and stainless steel	Yes

Table 2: List of topics and experiments in Form Five KBSM chemistry syllabus

	Topics & Experiments:	Small scale
1.	**Rate of Reaction**	
	Slow and fast reactions	Yes
	Average rate of reaction and instantaneous rate of reaction	Yes
	Effect of surface area on the rate of reaction	Yes
	Effect of concentration on the rate of reaction	Yes
	Effect of temperature on the rate of reaction	Yes
	Effect of catalyst on the rate of reaction	Yes
	Effect of the amount of catalyst on the rate of reaction	Yes
2.	**Carbon Compounds**	
	Combustion products of organic compounds	No
	Properties of alkanes and alkenes	Yes
	Preparation of ethanol by fermentation	Yes
	Chemical properties of ethanol	No
	Chemical properties of ethanoic acid	Yes
	Esters-laboratory preparation and physical properties	Yes
	Coagulation of latex	Yes
	Vulcanized rubber	No
	Elasticity of vulcanized and unvulcanized rubber	No
	Latex product	
3.	**Oxidation and Reduction**	
	Redox reaction as loss or gain of oxygen	Yes
	Change of iron(II) ions to iron(III) ions and vice versa	Yes
	Displacement of metals	Yes
	Displacement of halogens	Yes
	Transfer of electrons at a distance	Yes
	Effect of other metals on rusting	Yes
	Reactivity of metals with oxygen	Yes
	The position of carbon in the reactivity series of metals	Yes
	The position of hydrogen in the reactivity series of metals	Yes
	Oxidation and reduction in electrolytic cells	Yes
	Oxidation and reduction in chemical cells	Yes
4.	**Thermochemistry**	
	Exothermic and endothermic reactions	Yes
	Heat of precipitation	Yes
	Heat of displacement	Yes
	Heat of neutralization	Yes
	Heats of neutralization of acids and alkalis of different strength	Yes
	Heat of combustion of alcohols	Yes
5.	**Chemicals for Consumers**	
	Soap preparation process	Yes

Table 1 and 2 also showed the feasibility of using small scale approach in Malaysian chemistry syllabus. These indicate that the small scale chemistry approach can be adapted for most of the Form Four and Form Five chemistry experiments in the Malaysian secondary school chemistry syllabus. The implementation of small scale chemistry can reduce cost, time spent and chemical wastes generated since it uses much smaller quantities of chemicals compared to the traditional scale experiments.

This technique can reduce wastes up to 73 %, chemicals used up to 73 % and saves up to 75 % time spent for experiments in the form four syllabus. This technique also can reduce wastes up to 72 %, chemicals used up to 59 % and saves up to 53 % time spent for experiments in the form five syllabus. For quantitative experiments, such as an acid base titration, data using a 50 mL burette are comparable with those obtained using the microburette. Experiments can also be conducted individually by students. For experiments which involve syntheses of ethanol and ester and soap preparation, the amount of chemicals or reagents used can be reduced up to 10 %. This approach also can significantly reduce time spent for experiments which involve heating, filtration and drying.

Teachers' Feedback

Workshops and discussions were carried out with secondary school chemistry teachers to get their perceptions and views regarding this technique. A workshop was conducted with 66 chemistry teachers to expose them to hands-on practical activities involving small scale experimentation. The teachers were from various schools in Penang. The teachers attended a one-hour lecture on small scale chemistry followed by a hands-on session in the chemistry laboratory. All the teachers did the experiments individually. The teachers carried out five experiments as in the following:

(i) Confirmation test of cations in aqueous solutions
(ii) Electrolysis of aqueous solutions
(iii) Determination of end point for a neutralization reaction between an acid and a base
(iv) Electroplating of metals

(v) Reduction of copper(II) oxide

At the end of the lab session, an evaluation questionnaire was administered to the teachers. The purpose of the questionnaire is to get their feedback on the small scale chemistry experiments. The 5 points Likert scale was used, expressed in terms of 'strongly disagree','disagree', 'not sure','agree' and 'strongly agree'. To score the scale, the response options are credited 1, 2, 3, 4, 5 from the unfavourable to the favourable end. Five constructs were covered in the questionnaire which are:

a. The worksheet
b. The microscale kit
c. Evaluation of small scale experiments
d. Hands-on small scale experiments
e. Feasibility of small scale experiments

Open comments were also asked from the teachers regarding their opinions on small scale chemistry experimentations.

Table 3: Mean average and Standard deviation for all the construct

Constructs	Mean Average	Standard Deviation
(1) Worksheet	4.17	0.56
(2) Equipment	3.88	0.74
(3) Evaluation of small scale experiments	4.13	0.72
(4) Overall evaluation of small scale experiments	4.08	0.65
(5) Feasibility of small scale experiments	3.71	0.82

The mean score and standard deviation for each of the construct were calculated and results are shown in Table 3. The mean average values for all constructs are between 3.71 – 4.17. The chemistry teachers were favorable towards the worksheet and conducting small scale chemistry experiments especially in their overall evaluation on whether small scale chemistry experiments can meet the aims of practical work or not.

The comments from the chemistry teachers indicate that most of them had a positive view towards the small scale technique. They perceived that using the small scale approach is economical, student centred, very exciting, time saving, portable, flexible and easy to operate. It can also stimulate enjoyment in chemistry and produce less waste. They also commented that small scale experiments are suitable for some experiments especially those which focus on qualitative observations. This small scale approach can attract students with the equipment, skills and techniques and also can give new experiences to the teachers and students.

The negative views were difficulty in handling the equipment because the equipment were too small and hence could be easily dropped on the floor and lost, difficult to wash and also resulted in low precision for experiments involving measurement of volume, mass and heat. Vermaak (1997) reported that the open comments of the teachers in Malawi indicate that they were strongly supportive of the small scale approach.

Students' Feedback

Students' feedback towards small scale chemistry experimentations was conducted with 83 form four students from one school who worked individually using the microscale kit. Students perceptions questionnaire towards small scale chemistry experiments comprises 9 items. The 5-point Likert scale expressed in terms of 'strongly disagree','disagree', 'not sure','agree' and 'strongly agree' was used. To score the scale the response options were coded 1, 2, 3, 4, or 5 according to the responses from strongly disagree to strongly agree. The data for perceptions towards small scale experiments were reported in terms of frequencies and mean values for each individual item.

Table 4: Students' perception towards small scale chemistry experimentation

Number Of item	Perception towards small scale chemistry experiments	Percentage of responses (%) Disagree/ Strongly disagree	Unsure	Agree/ Strongly agree	Mean
4.1	It is difficult to handle the small scale equipment.	84.5	10.4	5.2	1.81
4.2	Doing the experiment myself makes me understand the experiment and concepts better.	7.7	16.7	75.6	3.95
4.3	The results of a small scale experiments are not observed easily.	57.2	31.2	11.7	2.40
4.4	I was afraid to try out these small scale experiments.	91.0	7.7	1.3	1.59
4.5	The experiments could be done quickly.	6.4	30.8	62.8	3.82
4.6	It is fun to do the small scale experiments.	1.3	1.3	97.4	4.38
4.7	I am keen to do more small scale experiments.	1.3	10.3	88.5	4.29
4.8	Small scale experiments are not real experiments.	71.8	24.4	3.9	2.00
4.9	Small scale chemistry equipment is a cheap version: we should use the real equipment.	43.6	46.2	10.2	2.47

Student perceptions towards the small scale chemistry experiments are presented in Table 4. The mean values for items 4.2, 4.5, 4.6 and 4.7 ranged from 3.82 to 4.38. The values showed a trend closer to '4' and above. This indicate that students agreed that by doing the experiments individually, they can understand the experiments and concepts better. They were also keen to do more experiments and perceived that small scale experiments were fun and could be done quickly. These findings are also supported by many researchers who found that conducting experiments with small scale techniques promoted time savings (McGuire *et al*., 1991, Bradley, 1999, Singh *et al*., 1999, Kelkar & Dhavale, 2000, Vermaak & Bradley, 2003, Tallmadge *et al*., 2004).

The mean values for items 4.1, 4.3, 4.4, 4.8 and 4.9 range from 1.59 to 2.47. The values showed a trend closer to '3' and lower. This indicated that students did not agree that the small scale equipment was difficult to handle, results of the experiments were not observed easily and that they were afraid to try out the experiment. They also did not agree that the small scale experiments were not real.

The students perceived that small scale experiments were easy to handle and they were very keen to do more experiments. They also understood the experiments and concepts better by doing experiments individually. These findings are supported by Vermaak (1997) who reported high positive mean values for the African pupils' perceptions of handling and managing the small scale experiments. They felt that small scale experiments were beneficial, fun to do and made them enjoy practical work. In contrast, McGuire, *et al*. (1991) found a persistent preference for traditional experiments over small scale experiments. However, his findings were limited to the number of experiments and students involved in his study.

Conclusions

The small scale chemistry approach can be adapted for most of the Form Four and Form Five chemistry experiments in the Malaysian secondary school chemistry syllabus. The implementation of small scale chemistry can reduce cost, time spent and chemical wastes generated since it uses much smaller quantities of chemicals compared to the traditional scale experiments. This technique can reduce wastes up to 73 %, chemicals used up to 73 % and saves up to 75 % time spent for experiments in the form four and form five syllabus. The teachers and students also had a positive view towards small scale chemistry experimentation. Thus, the small scale chemistry technique can be promoted to Malaysian schools based on the positive findings of this study.

References

Bradley, J.D. (1999). Hands-on practical chemistry for all. *Pure Applied Chemistry, 71*(5), 817 – 823.

Cooper, S., Conway, K. & Guseman, P. (1995). Making the most of microscale: using microchemistry as a tool to transform teaching. *The Science Teacher, 65*(1), 46-49.

Curriculum Development Center (2004).*Chemistry form four curriculum specifications, Integrated curriculum for secondary school,* Ministry of Education, Malaysia.

Curriculum Development Center (2006), *Chemistry Form Five Curriculum specifications, Integrated Curriculum for Secondary Schools,* Ministry of Education, Malaysia.

Hofstein, A. (2004). The laboratory in chemistry education: thirty years of experience with developments, implementation and research. *Chemistry Education Research and Practice, 5*(3), 247 -264.

Kelkar, S.L. & Dhavale, D.D. (2000). Microscale experiments in chemistry: the need of the new millenium. *Resonance, 5*(10), 24-31.

Layton, D. (1990). Student laboratory practice and the history and philosophy of science. In E.H Hegarty (Ed), *The student laboratory and the science curriculum*, London and New York : Routledge.

McGuire, P., Ealy, J. & Pickering, M. (1991). Microscale laboratory at the high school level: time efficiency and student response. *Journal of Chemical Education, 68*(10), 869 – 871.

National Microscale Chemistry Centre (1993).Why Microscale Chemistry [online].Available: http://www.silvertech.com/microscale.html (accessed 28 June 2005).

Singh, M.M., Szafran, Z. & Pike, R.M. (1999). Microscale chemistry and green chemistry: complementary pedagogies. *Journal of Chemical Education, 76*(12), 1684 – 1686.

Tallmadge, W., Homan, M., Ruth, C. & Bilek, G. (2004). A local pollution prevention group collaborates with a high school intermediate unit bringing the benefits of microscale chemistry to high school chemistry labs in the Lake Erie watershed. *Chemical Health & Safety.* July/August.

Vermaak, I. (1997). *Evaluation of cost-effective microscale equipment for a hands-on approach to chemistry practical work in secondary schools*. Ph.D. Thesis, Faculty of Science, University of the Witwatersrand, Johannesburg.

Vermaak, I. & Bradley, J. (2003). *New technologies for effective science education break the cost barrier*, paper presented at the British Educational Research Association Conference, Heriot-Watt University, Edinburg, Scotland, 11– 13 September.