DESIGNING MICRO CHEMISTRY EXPERIMENTATION FOR TEACHER TRAINEES IN A UNIVERSITY

[1]Ruby Hanson, [2]Lord Hunnuor Bobobee, [3]Kwarteng Ankrah Twumasi & [4]Victor Antwi
[1,2,&3]Department of Chemistry Education, University of Education, Winneba, **GHANA**
[4]Department of Physics Education, University of Education, Winneba, **GHANA**

ABSTRACT

Micro chemistry experimentation has come to reduce the usual traditional experimentation through miniature activities. In addition it has reduced activity time and the cost of resources significantly and yet provided personal hands-on experiences for learners. This study presents the design of micro chemistry experimentation for some quantitative and qualitative inorganic chemistry topics for first year undergraduate teacher trainees as well as to introduce a motivating way to teach and conduct chemistry activities. It basically set out to explore the designed low-cost practical approach that could contribute to improved laboratory practice in Ghana, in view of resource, time, and space constraints in a teaching institution. Overall findings showed that the micro chemistry approach made chemistry lessons interesting, interactive, and enabled learners to acquire many learning skills by themselves.

Keywords: Comboplate, wells, microchemistry kit, micro quantity, macro quantity.

INTRODUCTION

Microchemistry equipment has been in practice for almost two decades but is still unpopular in most institutions, as compared to the traditional macro equipment. Bradley (2000) introduced the micro chemistry kit (MCK) in underprivileged schools in South Africa to enhance their opportunities for learning science through hands-on activities. This idea and equipment were later adopted by the United Nations Educational, Scientific and Cultural Organisation- UNESCO (2006). The micro chemistry kit (MCK), which measures 14.5cm x 11cm x 5.5cm and contains a range of labelled miniature wells called the comboplate, forceps, gas collecting unit, glass rod, glass tube, microburner, pH guide, microspatula, syringes, propettes, and universal indicator. Micro chemistry (MC) activities are carried out by using much reduced amounts of chemicals in the comboplate. Thus, activities are safe and eliminate the fear of chemical explosions during chemistry experimentation. In addition, more time is available for reflection and discussions which are important parameters for building conception (Mafumiko, 2008). This assertion is confirmed by Hanson and Acquah (2014) in a study on how helping students to build collaborative skills through the use of micro equipment. Besides the reduction of work time and chemicals, generation of waste is also minimal. The precision of experiments is not at all compromised but enhanced (Abdullah, Mohamed & Ismail, 2008; Hanson, 2014). An earlier study by Kelkar and Dhavale (2000) showed that undergraduate students who engaged in micro chemistry activities gained better manipulative skills. Similar studies in high schools by Zakaria, Latip and Tantayanon (2012) also attest to positive conclusive remarks on the benefits of small lab kits and their effect on high school students. These positive reports on microscale chemistry (MSC) from across the globe prompted this current study. The aim of this study was to explore the possibility of designing micro scale activities as a means to perform activities not only in the laboratory, but in classrooms, due to space constraints, and to reduce over reliance on sophisticated, expensive and delicate equipment. It was also to expose learners to opportunities for active learning processes.

MSC activities can be performed in the home, classroom or standard chemical laboratory if one has a micro chemistry kit (MCK).The micro chemistry kit is a small lunch-like plastic box which contains miniature plasticware for performing activities on a micro scale. It can provide users with the opportunity to have personal experiences of hands-on activities. It requires reduced quantities of chemicals and comes as simple equipment. It has advantages which are related to cost saving, safety, environmental friendliness and conceptual gains (Hanson, 2014b). This study presents the general design of MCK experimentation for eight activities in a first year undergraduate chemistry class.

In the University of Education, Winneba (UEW) in Ghana, most of the first and second year chemistry activities are extensions of the secondary school chemistry syllabus. These topics are specially chosen so that graduate teachers from the institution gain adequate technological, pedagogical and content knowledge (TPCK) to help their students build sound science concepts upon graduation. However, large trainee numbers puts a strain on the institution’s resources. Some chemistry topics which are compatible to teach with the micro equipment are properties of acids and bases, strength of acids, salts, common ion effect, rates of reactions, basic titrimetry, stoichiometric reactions, solubility reactions, reactivity of elements and equilibrium, to mention a few. Each semester, the trainees carry out a maximum of eight activities. Thus, 16 MC activities, culled out of UEW’s Department of Chemistry Education Handbook (2013) have been developed for the first year trainees, eight of which are inorganic chemistry activities. The remaining eight, which are organic chemistry activities, would be tried out in their second semester of the same academic year.

Research design

This research formed part of a developmental research design. One of the prototypes was tried out in order to explore its validity and practicality before the final institutional documentation. A total of 46 first year chemistry major undergraduate teacher trainees participated in this study. They were purposely chosen because they were the group of students who were to read the topics under study. Besides, they had enrolled as students in the researchers’ courses. In view of information obtained from a first try-out, special guidelines were promulgated to enhance the design, transition and evaluation of the MCK activities.

1. Alignment with institutional and departmental curriculum requirements
2. Practical, simple activities that do not require ‘exotic’ chemicals and sophisticated, yet delicate labware
3. Activities to be easily achievable goal oriented exercises
4. Flexible, active, student-centred learning environments
5. Well spelt out assessment guidelines so that students would be encouraged

The 46 participants were observed with the help of a designed observation schedule (Appendix B) for 30 seconds each as they interpreted the activities in their own way and carried them out. They were engaged in a focus group interview at the end of the study session to assess their personal opinions about the MCK activity approach. The inter-rater value for the observed lessons was 92%.

The MCK were ordered from the Centre for Research and Development in Mathematics, Science and Technology Education (RADMASTE), Witwatersrand University, in South Africa. Eight activities were designed and developed from the first year chemistry syllabus (Department of Chemistry Education, 2013) and the RADMASTE Basic Manual (Durbach, Bell & Liwanga, 1996). Four of the developed activities will be presented in this paper.

1. **Reactivity of elements 1 (Metals)**
The reaction of groups 1 and 2 metals with water was to enable the teacher trainees gain a first-hand experience of how the reactivity of elements within a group and a period on the periodic table varied. The pH (acidity or basicity) of the resulting solution (after reaction) were determined by using universal indicator. They compared the rates of reactions of the metal-water activities with respect to the element's positions on the periodic table, predicted expected reactions and reactivities of other congeners within the same group and period and wrote balanced reaction equations. They also tested for gases which evolved (if any) from the reaction.

2. **Reactivity of elements 2 (Non-metals)**
This activity, involving the ions of group 17 elements was to enable the trainees to appreciate the order and degree of reactivity of the halogens towards halide salts. They were then to find out how the order of the halogens compared with their reactivities. In addition, they were required to predict the reactivity of F_2 (g) and give reasons. Balanced chemical equations were expected for all the reactions. The solutions required for the activities were 0.1M NaCl, 0.1M NaBr, and 0.1M NaI. Chlorine, bromine and iodine solutions were used as test solutions. The trainees observed that chlorine was the most reactive while iodine was the least reactive. This conclusion was drawn because they observed that chlorine reacted with Br^- and I^- salts while Br reacted only with I^- salt. Their clues to the reactivity of the elements were based on colour difference, which is quite easy to observe.

3. **Properties of acids and bases**
In this activity, safe household chemicals were employed so that trainees could have a first-hand experience with acids and bases, but the trainees were cautioned not to taste any chemicals in the laboratory. Vinegar, lemon juice, bicarbonate of soda and indicator papers were used. Aqueous HCl and NaOH were used as standard test solutions. Although trainees had been cautioned not to taste any chemical, they were however permitted to taste and describe the unique taste of lemon and vinegar as against that of bicarbonate of soda. They rubbed the aqueous NaOH between their fingers but did not taste it. They then tested the pH of solutions of the chemicals by using universal indicator and methyl orange.

A similar micro activity which employed the use of basic household chemicals was designed as part of an e-hybrid course to enable distance learners engage in practical activities at home by one of the researchers (Hanson, 2014a). Comparable observations were made. A designed table which summarises results obtained by students on properties of acids and bases is shown below.

Table 1: Results from the activity on acids and bases

Household chemical	Taste	Feel	pH(universal indicator)	Methyl orange	Red LP	Blue LP	Inference
Vinegar	Sour	Not slippery	< 7	Pink	No change	Red	**Acid**
Lemon juice	Sour	Not slippery	< 7	Pink	No change	Red	**Acid**
Bicarbonate of soda	Bitter	Slippery	>7	Yellow	Blue	No change	**Base**
NaOH	Bitter	Slippery	>7	Yellow	Blue	No change	**Base**
HCl	Sour	Not slippery	<7	Pink	No change	Red	**Acid**

LP = Litmus paper

4. Chemical stoichiometry

This activity enabled the trainees to engage in the stoichiometry of precipitation reactions by reacting aqueous lead nitrate with aqueous sodium iodide in graduated volumes. Approximate heights of precipitates formed were measured. Graphs of heights of the precipitates were drawn against volumes of lead nitrate and sodium iodide solutions. This approach enabled the trainees to measure, weigh and handle equipment with greater accuracy and precision. They then deduced from a volume to volume ratio (V_1/V_2) and a plot of a graph of volume against precipitate, the mole ratio for the reacting species. A similar activity had been conducted successfully by Hanson (2014a). They had to translate their gain in knowledge to situations such as what the new mole ratios would be if concentrations were doubled or halved. As usual, the expressions of correct reaction equations were expected.

Why employ the MCK and not the traditional macro equipment?

Data gathered from preliminary activities done with teacher trainees in the previous academic year indicated that trainees who engaged in the use of the MCK used fewer quantities and volumes of chemicals as compared to classes which used macro measures and equipment. There was virtually no demand on sophisticated, yet delicate glassware. Thus, the total cost of chemicals and equipment for the MCK group was lower than for the traditional macro group. Again, trainees who used the MCK spent less time at their work. They developed an independent positive attitude towards their study of inorganic chemistry. These assertions have been reiterated by Abdullah, Mohamed and Ismail (2008) in a similar work on the use of micro equipment in a secondary school in Malaysia. In this study however, the cost of chemicals was not assessed; only the quantities that were required by the trainees were. Tallmadge, Homan, Ruth and Bilek (2004) also found out in the UK that less waste was produced with the use of micro science equipment as against the enormous waste generated with macro equipment. In this study, trainees worked individually as against working in groups of between two and four with macro experiments where the latter is adopted to conserve excessive use of chemicals and production of waste. A comparative analysis of the amount of resources required for activities with the micro and macro equipment are presented in Table 2.

Table2: Comparison of amounts of chemicals required for the four activities in g/mL (n=46)

Experiment	**Desired chemicals**	**Macro quantities**	**Micro quantities**
1.Reactivity of metals	Na, K, Ca, and Mg metals, pH indicator, tap water	20 ml of water x 46 = 920ml of water 1cm x 1cm of Na (s) x 46 = 46 cm^2 1cm x 1cm of K (s) x 46 =46 cm^2 1cm x 1cm Mg (s) x 46 = 46 cm^2 5 granules/2.5g Ca x 46 = 230 granules/ 115 g	2 ml of water x 46 = 92 ml 2mm x 2mm of Na (s) x 46 = 1.84cm^2 Na (s) 2mm x 2mm of K (s) x 46 = 1.84 cm^2 K (s) 2mm x 2mm Mg (s) x 46 = 1.84 cm^2 1 granule/ 0.25g Ca x 46 = 46 granules /11.5g

2.Reactivity of non-metals	0.1M NaCl , 0.1M NaBr and 0.1M NaI	15 ml 0.1M NaCl x 46 = 690 ml 15 ml 0.1M NaBr x 46 = 690 ml 15 ml 0.1M NaI x 46 = 690 ml	1 ml 0.1M NaCl x 46 = 46ml 1 ml 0.1M NaBr x 46 = 46ml 1 ml 0.1M NaI x 46 =46ml
	Chlorine (aq)	100 ml chlorine (aq)	10ml chlorine (aq)
	Bromine (aq)	100ml bromine (aq)	10 ml bromine(aq)
	Iodine (aq)	100 ml iodine (aq)	10ml iodine (aq)
3.Properties of acids and bases	Solutions of vinegar, lemon, bicarbonate of soda, HCl (aq) and NaOH (aq)	5ml x 46 each of solutions of vinegar, lemon, bicarbonate of soda, HCl (aq) NaOH (aq) = 230ml each of solutions indicated	0.5 ml x 46 each of solutions of vinegar, lemon, bicarbonate of soda, HCl (aq) NaOH (aq) = 23 ml of each solution.
4.Chemical stoichiometry	0.25M $Pb(NO_3)_2(aq)$	60 ml of 0.25 M $Pb\ (NO_3)_2$ x46 = 2.76L	5 ml of 0.25 M $Pb\ (NO_3)_2$ x46 = 230 ml
	0.25 M NaI (aq)	60 ml of 0.25 M NaI x 46 = 2.76L	5 ml of 0.25 M NaI x 46 =230 ml

DISCUSSION

Observational data indicated that the trainees worked with greater ease and flexibility than they did with traditional standard macro glassware. They worked with greater precision, engaged in interactive discussions with their colleagues and tried out activities again if they were in doubt, in order to confirm or refute and construct their own ideas more confidently, based upon personal experience. These observations were confirmed during an interview with the trainees. A focus group interview with 8 of the trainees (in two sets of 4) who had been randomly selected indicated that designing and executing activities with the MCK was feasible, less costly, more fun, created less waste, was time saving and promoted an active learning environment. They explained that the dullness associated with the traditional activities was reduced. The trainees' assertions confirm what has been reported by Abdullah, Mohammed and Ismail (2008), Zakaria, Latip and Tantayanon (2012) and Hanson and Acquah (2014). This outcome was because the activities had been deliberately planned to as fully as possible engage the trainees to interact actively and effectively with the MCK as the rate at which activities could be accomplished could allow for extra engagement. Unlike comments made by other trainees in earlier studies by Hanson (2014b) on the inherent concept building nature of the MCK, trainees in this study did not make any comments on conception in the focus group interview. It was nevertheless implicit in their interpretation of activities and responses to post-lab questions. Majority of the trainees had positive experiences with the MCK activities and wanted more of it. They intimated that they felt motivated to try out activities in diverse ways without fear of undesired outcomes such as explosions. Besides, they did not feel guilty about over doing activities as very little chemical was required in each of their attempted activities. The questions for the focus interview can be found in Appendix A.

CONCLUSION

A trial of the designed activities showed that MCK activities constructed upon the outlined design guidelines were feasible for use in universities and would be feasible for use by trainees in their respective basic and high schools for active science teaching, especially in schools which are less endowed with science teaching materials in Ghana. This is because small amounts of chemicals and cheap apparatus which could be affordable to most resource-constrained schools are required. These assertions were intimated and implied by trainees in comments they made as they worked with the MCK and in a focus group semi-structured interview. The MCK activities are therefore a powerful implicit concept change approach to enhance teaching practices in university classrooms, besides saving cost and creating a safe, interactive, friendly learning environment.

RECOMMENDATION

The costs of chemicals and equipment, time spent in doing activities and amounts of waste produced could be assessed in follow up studies. This would make stronger, the case of the usefulness of the MCK activities over the traditional activities for which it would be compatible with.

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Appendix A

Semi-structured interview questions

1. What are your general impressions about the use of MCK experimentation?
2. Which activity did you find easy and interesting?
3. What did you like least about the MCK and experimentation?
4. Would it be possible to extend the use of the MCK to other chemistry activities?
5. What other activities could be designed for use with the MCK?

Appendix B

Observation guide

Trainees' behaviours	Symbolic behaviour
1. Shows and applies literacy skills	
2. Expands learning by using scientific language	
3. Interprets theoretical instruction into activity	
4. Recognises procedural errors and corrects them	
5. Discusses ideas that are intellectually challenging	
6. Develops variety of explanations and shares ideas	
7. Evidence of working with MCK	
8. Evidence of gaining learning skills from MCK activity	
9. Answers focus questions conceptually based on information gathered from activity	
10. Uses newly learned concept to answer extension question	

Score guide: ‴ = observed behaviour ″= partially observed behaviour ′= behaviour not observed