Research Article

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The Potential of *Micro-scale Chemistry Experimentation* in enhancing teaching and learning of secondary chemistry: Experiences from Tanzania Classrooms

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Abstract：This paper reports on the views and experiences of the teachers and students participating in the summative evaluation phase of a micro-scale chemistry instruction scenario via developed examplary curriculum materials (the MSCE approach) to support teachers with implementation of practical work in A-level chemistry classes in Tanzania.The evaluation involved field testing of the materials to investigate the effectiveness of the MSCE approach when compared to "traditional" teaching approaches, on Form 5 (13th grade) students' learning of solubility and precipitation. A total of 195 science students and their teachers from four classes in four different high schools participated in the study. Two teachers taught solubility and precipitation topic with micro-scale practical activities to an experimental group (N=88) and the other two teachers taught the same content topic using regular teaching approaches to a control group (N=107). The research design made use of triangulation procedures, involving student achievement test, observation of the use of MSCE approach in context by teachers and students, interviews and questionnaires. The results of the study indicate that the overall teachers' and students' reactions to the MSCE approach were vastly positive.Teachers reported that their participation in the MSCE study had been a professionally developing experience. They had become aware of the opportunities of using a new approach to conduct practical work with minimum resources to support student learning. Similary, the findings indicate that most students' were excited with the micro-scale experiments experience and they it easy, more interactive and enjoyable, allowing them to carry out experiments for themselves, collaborate with peers, and communicate with their teachers freely. Besides the affective outcomes, students exposed to this approach appeared to develop better scientific reasoning skills by engaging in small group discussions and reflections during micro-scale hands-on/minds-on practical activities. This paper concludes that the MSCE approach developed in this study with exemplary lesson materials, containing adequate procedural specifications, are feasible for use in A-level chemistry classes and are effective in providing positive learning experiences for students.

Keywords：Development research, Micro-scale chemistry, practical work , currilum materials, validity, practicality and effectiveness.

INTRODUCTION

In the middle of the 1990s a situational analysis investigated science teaching in Tanzanian secondary schools (Chonjo, Osaki, Possi & Mrutu, 1996). It became apparent that there were deep-rooted problems in the teaching and learning of science in the secondary education sub-sector. Problems in pedagogy, curriculum, examinations, laboratories, equipment, and consumables were among the most prevalent in the report. The report revealed that teachers' pedagogical skills were weak, most teachers had inadequate practical skills or lacked competence, and continued to lecture, with a focus on the next examinations rather than promoting understanding. Access to regular INSET programmes for teachers to update their knowledge and teaching skills appeared to be limited. Likewise, the syllabuses were overloaded with content while examination requirements compelled teachers to teach in a rush to cover the long syllabus. On laboratories, equipment, and consumables, the situation was reported as critical. Resources for practical work were reported to be very limited. Practical work was rarely happening in most schools because standard equipment and chemicals were too expensive to purchase. Subsequent studies (Chonjo & Welford,2001; Kibga, 2004; Leeuw, 2003;Mafumiko,1998) showed that the situation in most schools did not significantly improve, especially in relation to resources and the conduct of practical work, shortage of science and mathematics teachers, as well as shortage of textbooks.

In view of these findings, the need for improvement of science and mathematics teaching in the country was seen as inevitable. Improving teaching and learning materials (e.g. textbooks and laboratory facilities) in the schools and strengthening both pre-service and in-service science teacher education were considered priority areas for improvement efforts. Among the improvement strategies were the establishment of collaborative donor funded science education projects aimed at improving the teaching and learning of science and mathematics in the country (Osaki, 2002, 2007). One of these projects was the Teacher Education Assistance in Mathematics and Science (TEAMS) project.The TEAMS project focused on science teacher education, both pre-service and in-service, and worked mainly with undergraduates at the University of Dar es Salaam and A-level science teachers in Tanzania. Among the project activities were research and development of teaching and learning materials, capacity building by training science education researchers and leaders (Ottevanger, de Feiter, Osaki & van den Akker, 2005). The Micro-Scale Chemistry Experimentation (MSCE) study was carried out within the framework the TEAMS project. The underlying assumption of MSCE is *less is more*: less costs, less demand on chemicals and equipment, less 'chalk and talk' teaching, for more understanding, more motivation, more safety, and more 'hands-on and minds-on' learning activities.

Micro-scale experimentation in practical chemistry teaching

Since the 19th century, instructional laboratories in chemistry were based on carrying out experiments with multi-gram quantities of materials. But into the 1980's, with continuing economic pressure in education and increased environmental awareness, the need to carry out practical chemistry on a much more reduced scale, in order to save chemicals, time, and ease disposal problems became increasingly important. Since then micro-scale chemistry has been a part of laboratory practice and teaching, particularly at college and university levels (Towse, 1998).

Micro-scale chemistry refers to an approach or technique for carrying out experiments on a reduced scale using small quantities of chemicals and often (but not always) with simple equipment (Rayner- Canhan, 1994; Skinner, 1997). Micro-scale chemistry involves scaling down chemical reagents to an absolute minimum than those used in traditional laboratories; and shifting from glassware to modern polymer or plastic materials (Bhanumati, 1997).The advantages of this approach are numerous and well-attested (Bradley, 1999; Rayner-Canham, 1994; Skinner; 1997). Such advanatages are essentially related to *cost savings, time savings, improvement in laboratory safety and air qualitty, and environment-friendlines.* Beyond the economical, environmental, and safety advantages, micro-scale chemistry offers, a number of pedagogical advantages including the following:

- It engages students in hands-on learning experiences and provides more opportunity for collaborative learning;
- Students gain confidence in their own ability to work with small amounts of materials;
- It is much faster to carry out, allowing students to

accomplish much more in the laboratory;

- Students enjoy it because the dullness usually associated with laboratory work is reduced since students are not sitting around and waiting for something to happen;
- It instils in students the ethics of resource conservation.

The benefits of micro-scale in the context of developing countries are exemplified by a small number of studies only (Bradley, 2000; Thulstrup, 1999; Towse, 1998). The review by Towse (1998) on the microscale approach cites several studies (e.g. Bradley & Vermaak, 1996; Caro, 1995; Corley, 1995; Schultze, 1996) of high school students from different contexts in which strong positive attitudes toward microscale chemistry were exhibited. Among the findings from these studies are: enhancement of student laboratory skills, more focus on understanding of the concepts rather than on the manipulation of equipment, more opportunity for discussion and reflections, experiments are easy and fun for students.

However, a few limitations exists in the practice of micro-scale chemistry techniques (Bradley,1999). The most important limitation is temperature. Experiments involving heating, and concentrated acids (e.g. nitric acid) are not easily feasible due to the plastic nature of the equipment usually used in the micro-scale chemistry methods. Such experiments will need modified micro-chemistry (Bradley, 1999). It can thus be argued that micro-scale chemistry form an important part of practical work approach but it cannot be applied for every topic in a given syllabus.

Although many benefits of micro-scale chemistry can be listed, empirical evidence of its impact on classroom practices and student learning, specifically at the secondary school level, appears to be very limited. The few studies that have been conducted have concentrated mostly on investigating the economic aspects of micro-scale methods in the conduct of practical work in school chemistry (Rayner-Canham; 1994, McGuire, Ealy & Pickering, 1991). South Africa, Cameroon, Uganda, and Kenya have been cited as examples within Africa where micro-scale chemistry has received a very positive response by both teachers and students (Sia, 2002).

The positive results of microscale chemistry from past studies seemed encouraging enough for Tanzania, where both human and material resources are inadequate in most schools. Moreover, an initial exploration on the use of microscale chemistry methods in Tanzanian secondary schools showed the possibility of using micrsocale experiments in secondary chemistry teaching in Tanzania (Mafumiko,1998). Findings from this exploration indicated that teachers found microscale experiments could be easy to implement in the classroom and had the potential to address some of their concerns, such as shortage of chemicals and equipment, safety and time constraints. Although this study was limited to teachers only it provided baseline data for the Micro-Scale Chemistry Experimentation (MSCE) study that would also involve students in real classroom settings. Thus, a follow-up study focusing on the design, development, and implementation of micro-scale chemistry practical activities was set to test the practicality and effectiveness of the approach in a Tanzanian school environment.

Purpose

The purpose of the MSCE study to explore the possibility to use micro-scale chemistry approach as a means to perform practical activities in chemistry classes, hence reducing the need for highly equipped laboratories, but also providing opportunities for students to engage in a process of active learning. Specifically the study was set up to design, develop and evaluate a micro-scale chemistry scenario with exemplary curriculum materials as the support structure that could assist teachers with the implementation of more practical work in A-level chemistry classes.

METHOD

The MSCE study adopted the development research approach (van den Akker, 2002). The overall design of the study comprised of three phases. The first phase, front-end analysis, included a context analysis and a literature review. The context analysis sought to gain insights into the situation of teaching and learning science in Tanzanian secondary schools with particular attention to implementation challenges of chemistry practical work. The literature review aimed at gaining insights into the intentions, practices and effectiveness of practical work in science education at international, regional and local levels. The main focus of the review was on gaining insights into micro-scale chemistry as a promising example of low-cost methods for promoting practical work in chemistry teaching. The second phase involved development of prototypes of MSCE exemplary curriculum materials. In this stage, a succession of prototypes were developed through the cyclic approach of design, development and formative evaluation activities (Nieveen, 1999 & van den Akker, 2002). The formative evaluation (carried via expert appraisals and classroom try-outs) aimed at increasing the quality of prototypes. Evaluation of the first version put emphasis on obtaining indications for improvement of validity and practicality of the intervention (Mafumiko & Ottevanger, 2004), while in the evaluation of the subsequent prototypes the emphasis shifted to practicality and effectiveness of the MSCE approach. The third phase of the study focused on the effectiveness of the intervention (See Appendix B for example of final version of the materials). In this phase a quasi experimental research approach, non-equivalent control group design (Creswell, 2002; Martens, 1998) was used to evaluate the initial impact of micro-scale curriculum materials on student learning of a specific syllabus topic as comapared to the approaches teachers normally use in teaching the topic.

This paper focuses on the third phase of the study: the effectiveness of the intervention-"*the MSCE approach to chemistry practical work*" developed and was introduced via examplary curriculum materials as vehicle for supporting teachers in its initial implementation in Tanzanian A-level chemistry classes.

Participants and Setting

A total of 195 science students, 145 male and 50 female aged between 17–19 years participated in the study. They were enrolled in Form 5 (13^{th} grade) science classes from four selected government secondary schools in two regions, Dar es Salaam and Iringa. Two schools were involved in each region, one school in each region as experimental (treatment) group and as a control group. Out of the 195 students, 107 came from the control schools and were all boys. Eighty students including 38 male and 50 female came from the experimental schools. Selection of the schools was based on purposive sampling (Cohen, Manion & Morrison, 2000; Krathwohl, 1998).Selected schools were those who had shown (a) willingness of the chemistry teachers and school administration to participate in the study established during the researchers' pre-field visits); (b) availability of a reasonable number (at least 50 students) of Form 5 students enrolled in the Physics, Chemistry, and Biology 'PCB' stream (c) match topic of investigation and teachers' schemes of work; and (d) reliable means of transport to and from the regions and schools.

Participating teachers at each school were those who were teaching the study classes. Teachers in charge of practical work at each experimental schools were partly involved in providing additional support for class supervision. All the four teachers were male with chemistry teaching experience at A-level ranging from 1 to 2 years. Two teachers (one for experimental class and another the control class) had bachelor of science with education degrees and teaching diplomas. The other two teachers (one for experimental class and another for the control class) had bachelor degrees in Agricultural science. None of the teachers had been exposed to any kind of formal in-service education and training after their undergraduate programmes.

It can be noted that the sample had an unequal distribution of boys and girls between the experimental and control group classes. There were fewer girls than boys and all were in the experimental group. However, this unequal gender distribution favoured the control group in view of other findings (Urassa & Osaki, 2002) which showed that secondary school girls in Tanzania normally perform more poorly in science subjects than boys.

Instruments

Two assessment instruments were used in addition to direct classroom observations, students group interview and teacher interview. The instruments included student achievement test, and questionnaire.

A 15-item achievement test was developed by the researcher to measure the student understanding of solubility and precipitation concepts and principles. The test items were constructed based on the Tanzanian A-level Chemistry syllabus. The content of the test items included basic concepts related to solubility of ionic compounds, dissolution and precipitation reactions, use of solubility rules and precipitation reactions in qualitative analysis, solubility product, and the common ion effect.

Prior to administration, the test was validated through a review by two university lecturers with expertise in chemistry and chemistry education and one experienced A-level chemistry teacher. The test was also pilot-tested in one A-level secondary school with few students of the same grade level as students in the study schools. Following the students feedback the test items were improved, and the final version was prepared for use in both pre-test and post test measurements. The test consisted of 13 multiple choice items and two short-answer items (see Appendices A). A total of 195 students from both the experimental and control groups took the test. The reliability of the test was estimated based on the multiple choice item responses and turned out to be quite low (alpha = 0.51). The reliability of short answer items was 0.69.

To assesse the student experiences and opinions about the MSCE based chemistry lessons all students were invited to respond to a semi-strucured questionnaire at the end of the classroom implementation of the MSCE approach at each experimental school. The questionnaire consisted of 27 close-ended items and three open-ended items. A scale of 1 to 5 was presented for each statement item (1 = strongly disagree, 5 = strongly agree) for the first 15 items for students to indicate their views in relation to learning chemistry, group interaction, active participation, enjoyment of chemistry, and laboratory learning skills with the MSCE approach. Similarly, a scale of 1 to 5 was given for each statement item (1= not helpful at all, 5 = very helpful) for the students to indicate their response to other 12 statements by indicating how helpful were the differents learning activities in the MSCE based lessons. The open-ended questions focused on what students liked and/or disliked about the MSCE approach, and whether they experienced any difference between MSCE-based lessons and the 'regular' chemistry lessons.An estimation of the internal consistency (Cronbach alpha) of the questionnaire based on the close-ended items was found to be 0.78.

Classroom observational data in the experimental classes were obtained with the help of a curriculum profile (van den Akker & Voogt,1994), developed by the researcher, with some items from adapted from Ottevanger (2001) and Tilya (2003). Direct classroom observations aimed at observing how teachers and students were using the materials and the MSCE approach in their context. Classroom observations in the control classes aimed at gaining insights into the classroom implementation of solubility and precipitation lessons using the regular 'traditional' teaching methods. The observations were guided by the same curriculum profile used in the experimental classes but considered only items applicable to the lessons. In addition, notes were also taken during the lessons to provide a descriptive summary of the classroom activities.

RESULTS AND DISCUSSION

The effectiness of the MSCE intervention was assessed by focusing on the intention and design specifications of the MSCE materials in relation to its actual use in the classroom, students' experiences with, and teachers' opinions about the MSCE approach.

Overall impression

Overall, the results of the evaluation showed that both teachers and students had positive experiences with micro-scale chemistry lesson activities. While teachers responses indicated that they liked and appreciated their exposure to a new, simple, quick and a relatively inexpensive approach to chemistry practical work, most students were excited with the micro-scale chemistry experience.They reported to have enjoyed the lessons, in particular by engaging themselves in doing the experiments and sharing ideas in groups.

The overwhelming positive reactions of both teachers and students to the micro-scale chemistry experimental work in this context could be an indication of the appealing nature of the approach (new, interesting, easy to carry out, fast). On the other hand, it could be an indication of an appreciation of the opportunity to do practical work, because practical lessons are normally hardly done in Form 5 chemistry lessons. In this context it is reasonable to expect that students would react positively to any approach which involves them in doing practical work. However, evidence from previous research supports the first perspective (Bradley, 2000). In his investigation on the impact of micro-science on pre-service and in-service teacher education heports that tutors who used micro-scale chemistry kits found practical sessions much easier than before and the students seemed much more interested in practical activities.

Teachers' experiences and opinions about the MSCE approach

Responses from the reflective interview revealed that participant teachers had positive opinions about

Table 1: *Students' opinions about MSCE practical lessons (N = 83)*

Did you feel that Micro-Scale Chemistry practical activities:	N^a	Mean^b	Standard deviation	A/SA in %	strongly
1. Were linked to other parts of chemistry	77	3.9	0.94	70.2	
2. Helped you understand more about solubility and precipitation	83	4.7	0.53	97.6	
3. Helped you understand more about qualitative analysis	81	4.2	0.75	88.9	
4. Made you feel like learning more about the subject	82	4.2	0.77	90.2	
5. Helped you prepare for other topics in the syllabus	82	3.8	0.96	73.2	
6. Clarified some of concepts that you had difficulties with	83	4.2	0.76	90.3	
7. Made you enjoy your chemistry classes	83	4.5	0.50	100.0	
8. Made your head think	83	4.2	0.81	91.4	
9. Have given you confidence to carry out experiments by yourself	83	4.4	0.72	91.6	
10. Provided you with the opportunity to use materials & equipment	82	4.0	0.85	81.7	
11. Made you feel like a Chemist	83	4.3	0.75	91.4	
12. Made you actively participate in the lesson	83	4.4	0.62	95.2	
13. Increased your co-operation and sharing ideas with fellow students	83	4.5	0.61	96.4	
14. Made you feel very responsible about safety and environment	83	4.0	0.86	85.9	
15. Exposed you to an easier way of conducting experiments	83	4.4	0.77	90.4	

Note: Na: number of respondents per item; b: students provided answers to each item on the basis of a scale of 1 to 5, with 1 = strongly disagree (DA) and 5 = strongly agree (SA).

their own learning experiences with MSCE approach, as well as that of the students. Following personal experiences with micro-scale experiments in the introductory workshop, felt that their scope of practical work had been increased. They felt that new approach provide them with an opportunity to do practical work even with large number of students using minimum resources. Teachers' responses also indicated that their involvement in the MSCE study their subject matter knowledge and teaching skills regarding solubility and precipitation had been enhanced. Furthermore, teachers' opinions indicated that micro-scale practical activities were very helpful in engaging students actively in the learning process, and stimulating interest in chemistry lessons. Furthermore, teachers' views indicated that micro-scale experimental work were very useful in engaging students actively in the learning process, stimulating interest in chemistry lessons, and practical work in particular.

The teachers' positive reactions to the MSCE curriculum materials supports other findings of past studies (Grossmann & Thompson, 2004; Ottevanger, 2001) which showed that curriculum materials play quite a significant role in scaffolding new teacher learning as they provide teachers with opportunity to try out new ideas and teaching strategies in their classes. In this study, teachers felt that they gained some new ideas, such as logical and simple structure of students' experiments and improvisation of apparatus, and how to incorporate pre-laboratory exercises in the practical lessons. The results are consistent with the findings of Ottevanger (2001), which showed that teacher support materials help teachers overcome the activation barrier that characterizes the change to an innovative teaching methodology. The findings of the MSCE study have shown that the materials provided teachers with adequate support in their lesson preparation as well as in the lesson implementation. However, classroom observational data indicated that praticipant teachers had challenges with supervsion and monitoring of students' learning activities in small groups. The active nature of students' participation in the experiments and discussion in groups made teachers loose control of time for other parts of the lesson. In most groups, discussion took

Table 2: *Student' opinions on specific activities of the MSCE lessons (N= 83)*

How useful have you found the following activities in helping you learn chemistry with Micro-Scale Chemistry approach?	N^{a}	Mean^{b}	Standard deviation	Helpful or very helpful in %
Pre-laboratory work				
1.Doing pre-lab exercises	83	4.0	1.02	78.3
2.Teacher not explaining everything in the activity	82	2.5	1.28	26.8
Small group practical activity				
3.Predicting what will happen in a particular experiment	81	3.9	0.86	76.5
4.Doing experiments myself	83	4.4	0.99	85.6
5.Using instruction from the student worksheet	82	3.9	1.05	73.1
6.Using plastic sheets to perform experiments	82	4.3	0.91	86.6
7.Using grid paper to record observations	83	3.9	1.00	78.3
8.Analyzing and explaining experimental results	83	4.2	0.85	84.4
Post-lab discussion				
9.Discussing experimental results in small groups	82	4.4	0.91	87.6
10.Discussing experimental results as a whole class	83	4.0	1.20	72.3
11.Teacher explaining the chemistry behind each experiment	83	4.0	1.19	69.9
Follow-up assignment				
12.Doing homework myself	83	4.6	0.81	90.4

Note: Na - number of respondents per item; b - students provided answers to each item on the basis of a scale of 1 to 5 with 1= not helpful at all, 5 = very helpful.

longer time than that suggested in the materials and only short time was left for group presentation and lesson conclusion.

Students experiences and opinions about MSCE approach

Following the last classroom observations students were invited to express their opinions about chemistry lessons with micro-scale chemisrty experimental work to complete a 30-item questionnaire. Student responses were highly positive (see mean scores in Tables1&2). For example, students indicated that they enjoyed chemistry lessons with micro-scale practical activities because it made them actively participate in the lesson, it helped them understand more about solubility and precipitation topic, got confidence to carry out experiments by themselves, and liked discussing experimental results in small groups because it increased their cooperation and sharing of ideas among classmates and the teacher. Students views about the MSCE lessons were also expresed through their responses to open-ended questions and interview. Their responses corroborated quite well with the findings obtained from the close-ended items, but also provided supplementary information on their experiences with the MSCE approach such as aspects of the lessons liked (did notl like) most and the reasons. Examples of aspects the liked most include use of plastic sheets, doing experiments by themselves and pre-lab exercises. Sharing of chemical among small groups was the aspect that few students indicated to dislike most.

In terms of the differences between the MSCE approach the regular teaching approaches, students responses differences mainly in four aspects:-student participation and classroom interactions, hands/ minds-on activities, motivation and pre-laboratory exercises as illustrated by the following examples of individual student responses:

> "*In MSCE lessons, we were free to ask questions and express our ideas, while in normal classes we are not always free because, when we ask questions, our teachers normally think we make unnecessary challenges and when we want to express what we understand our fellow students think that we are proud of ourselves*".
>
> "*These lessons were so different because there was good cooperation between students to students and also between the teacher and students so you can find it is so interesting and gives the student the courage not to miss the lesson or period different from our regular chemistry class*".

During the interview conversations,for example, students mentioned experiments involving mixing lead nitrate and potassium crystals in a water drop (experiment 2; lesson 1) and those of mixing different solutions of

Table 3: *Differences between pre- and post-test performance on multiple choice items for the experimental and control groups***

Item	Item category	Experimental (N=88)			Control (N=107)		
		% of correct responses		*Sign.(x^2)*	*% of correct responses*		*Sign. (x^2)*
1	*Comprehension*: measures students' ability to grasp meaning of dissolution and relate it to real life situation. [Practical oriented and reflects MSCE approach]	Pre Post	8.0 37.5	0.351*	Pre Post	11.8 20.4	0.117
7	*Application /analysis*: measures students' ability to apply solubility rules and experimental data to solve a given practical problem. [Practical oriented and reflects MSCE approach]	Pre Post	47.7 79.5	0.331*	Pre Post	59.0 62.2	0.032
9	*Application/ Analysis*: measures students' ability to analyze possible chemical reactions and apply solubility rules to make conclusions regarding precipitation. [Practical oriented question and reflects MSCE approach]	Pre Post	31.8 61.4	0.296*	Pre Post	34.2 39.8	0.058
4	*Knowledge*: measures ability to recognize correct definitions of chemical terms or concepts. [Reflects regular teaching approaches]	Pre Post	40.9 53.4	0.125	Pre Post	50.3 76.5	0.265*
13	*Comprehension*: tests students' ability to remember and use relationships between chemical concepts to predict occurrence of precipitation. [Reflects regular teaching approaches]	Pre Post	52.3 55.7	0.034	Pre Post	54.0 73.7	0.058*

Note:*Statistically significant ($p < 0.05$); ** differences based on items with significant gains.

cations and anions using drops of solution (experiments in lesson 2) as their most exciting experiences with MSCE based lessons. Students explained that these experiments provided them with many valuable learning experiences on solubility of different salts and helped them to understand the dissolving and precipitation process as is further illustrated by the following response:

"*through the experiment of lead nitrate and potassium iodide crystals in a water drop, we were able to 'witness' how ions move. We placed the white crystals of the two salts at the edge of water drop on different sides, we saw them disappearing in water and after sometime a yellow solid appeared at the middle of the water drop*".

A few students, however, expressed some concerns on the possibility of contamination between different reagents due to small boxes on the reaction grids, and sharing of chemicals among small groups. They noted that if students are not keen in following the instructions it is easy to mix the reagents or the droppers, and could lead experimental errors. Some students also felt that the pre-lab questions were many and cognitively challenging to be completed within the practical sessions.

Impact of the MSCE approach on cognitive learning

In oder to examine the initial impact of micro-scale chemistry approach on student cognitive learning an achievement test was administered before and after classroom implementation of solubility and precipitation lessons to all participating students. The pre-test and post-test results were analyzed on an item level.

An analysis of the pre-test and post-test data showed that for only five the multiple choice items (questions 1, 4, 7, 9 & 13 in Appndix A) could a significant learning gain be determined for either the experimental or control group. It was therefore decided to focus on these five items. Chi-square test analysis showed a significant learning gain for the experimental group for items 1, 7, and 9 (see Table 5). For the control group a significant learning gain could be determined for item 4 and item 13 (see Table 5). A content analysis of the five multiple choice items revealed that items 1, 7, and 9 in particular reflected the MSCE approach. These items emphasized application of chemistry concepts and principles to solve a given problem (i.e. emphasized more on understanding chemistry processes than content

Table 4. *Differences between pre -and post-test performance on short-answer items for the experimental and control groups*

Item	Item characteristics	% students that answered the item correctly						
		Experimental (n=88)			Control (n=107)			
		Pre - test	*Post- test*	*Gain*	*Pre - test*	*Post- test*	*Gain*	*P**
14a	*Application*: measures students' ability to apply chemical principles and rules to solve a problem; and represent chemical processes in an appropriate scientific language. [Reflects the MSCE approach]	2.3	44.3	42.0	5.7	9.4	3.7	0.000
14b	*Application*: measures students' ability to apply learned concepts and principles as well as ability to represent chemical processes in an appropriate scientific language. [Reflects the MSCE approach]	2.3	37.5	35.2	4.7	7.5	2.8	0.000
14c	*Application*: measures students' ability to apply chemical principles and rules to solve a problem; and represent chemical processes in an appropriate scientific language. [Reflects the MSCE approach]	2.3	28.4	26.1	3.8	3.8	0.0	0.000
14d	*Application*: measures students' ability to apply chemical principles and rules to solve a problem; and represent chemical processes in an appropriate scientific language. [Reflects the MSCE approach]	1.1	30.7	29.6	3.8	1.9	-1.9	0.001
14e	*Analysis*: measures students' ability to make and defend a scientific argument from given data. [Reflects the MSCE approach]	2.3	17.0	14.7	1.9	1.9	0.0	0.003
15a	*Comprehension*: measures students' ability to identify the distingui-shing property between two closely related concepts/terms. [Reflects regular teaching approaches]	1.1	23.9	22.8	8.5	17.0	8.5	0.027
15b	*Application*: measures students' ability to interpret and use solubi-lity rules to life-related situations [Reflects both teaching approaches]	12.5	33.0	20.5	12.3	17.9	5.6	0.026
15c	*Comprehension*: measures ability to recognize relationships between given concepts and use it to explain a problem [Reflects regular teaching approaches]	10.2	34.1	23.9	21.7	34.0	12.3	0.129

Note:*Significant ($p < 0.05$) difference in learning gain between the experimental and control group.

acquisition). Items 4 and 13 reflected knowledge that is typically acquired in a more traditional lesson. These items emphasized understanding of specific chemistry concepts and their relationship.

A t-test was used to examine learning gain on the short-answer items of the experimental and control group. Comparison between the experimental and control group gain showed that for all items, except one (item 15c), a significant difference could be established in favour of the experimental group (Table 6). This meant that students from experimental classes significantly improved their scores after learning the topic as compared to those from the control classes. On the other hand, the results showed that although both groups did improve their scores on item 15c, the difference in gain between the two groups was not large enough to be statistically significant (Table 5). The results for item 15c could possibly be explained by the following reasons: (1) the concept tested was easy and students from both groups could easily learn by heart (2) the nature of the item probably gave students a clue to the right answer, because it involved choosing between two responses, without demanding a supporting argument.

The above results indicate that students' experiences with the micro-scale chemistry lessons were mostly positive. Criticism and negative opinions were rare, coming from just a few individual students. On the other hand, given such positive results, it can be assumed that integrating micro-scale experiments into teaching would help increase student motivation and interest in chemistry. This assumption is consistent with the views of Hofstein and Lunetta (2004) that the laboratory, as a unique social setting, has (when activities are organized effectively) great potential to enhance social interactions that can contribute positively to developing attitudes and cognitive growth. Similarly, the findings of this study strongly suggest that the use of micro-scale experiments in chemistry teaching have the potential to promote an active classroom learning environment through small group activities. The above results support previous work in micro-scale chemistry (Bradley, 2000; Vermaak, 1997, Towse, 1998) and seem to be consistent with other research which shows that students' participation in practical activities leads not only to greater understanding but also to greater interest in the study of chemistry (Demircioglu, Ayas, & Domircioglu, 2005; Thompson & Soyibo, 2002; Wachanga & Mwangi, 2004).

Conclusions

One of the lessons learned from the literature is that exposing teachers to new ideas, resources, and opportunities broadens their awareness of possibilities for change and fosters a sense that alternatives are possible (van den Akker, 1998).

The MSCE study was undertaken to explore the possible use of micro-scale chemistry to practical work in order to promote an active learning environment based on low equipment and consumable demand, the ultimate goal being to improve teaching and learning of secondary school chemistry in Tanzania. The conclusion drawn in this paper is that Micro-Scale Chemistry Experimentation approach introduced via carefully designed and validated curriculum materials, has the potential for improving teaching and learning practices in A-level chemistry classes in Tanzania. The findings suggest that micro-scale curriculum materials developed with adequate procedural specifications, are feasible for use in A-level chemistry classes and are effective in providing positive learning experiences for students. Evidence from the summative evaluation shows that the MSCE approach is not only easy to use but also makes chemistry classes more interactive, interesting, and enjoyable, allowing students to carry out experiments for themselves, collaborate with peers, and communicate with their teachers freely. Besides the affective outcomes, the findings suggest that students develop better reasoning skills by engaging in micro-scale (hands-on/minds-on) activities. It is recommended that further work be carried out with the micro-scale chemistry experimental work so that it can be spread to more school.

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Appendix A

Student achievement test

Name---------- School-------------date---------- Class--------

Time Allocated: 1 ½ hours

INSTRUCTIONS: Choose the CORRECT answer and mark with a tick (√) against the letter of the answer for question items 1-13. Use the space provided under each question to write answers for questions 14 and 15.

1. If powder soap (for example, Foma) is mixed with water a soap solution is obtained. Which process below correctly summarises this situation?

a. Solution
b. Dissolution
c. Precipitation
d. Solubility

2. A solute is most likely to be highly soluble in a solvent if:

a. the solute is ionic or polar and the solvent is non-polar
b. the solute is ionic or polar and the solvent is polar
c. the solute is non-polar and the solvent is polar
d. the solute is non-polar and the solvent is ionic

3. Water can dissolve solid ionic compounds at a certain temperature. Which of the following equations best represents the dissolving of NaCl in water?

a. $NaCl(s) \longrightarrow Na^+(aq) + Cl^-(aq)$
b. $NaCl(s) \longrightarrow Na\,(aq) + Cl\,(aq)$
c. $NaCl(s) \longrightarrow Na^+ + Cl^-$
d. $NaCl(s) \longrightarrow NaCl + H2O$

4. One of the following chemical concept / term describes the normal maximum quantity for solute in a solvent (expressed in---grams/100grams of water) at a certain temperature.

a. Solubility
b. Solute
c. Solvent
d. Concentration

5. Combining aqueous solutions of $BaCl_2$ and Na_2SO_4 gives a white precipitate of $BaSO_4$. Which ion(s) do not take part in the reaction?

a. Ba^{2+} only
b. Ba^{2+} and SO_4^{2-}
c. Na^+ only
d. $Na^+$and Cl-

Use the information given in table 4.1 (see attached sheet of paper) to answer questions 6-9.

6.Which one of the following compounds would be insoluble in water at room temperature?

a. NaI
b. $Ba(OH)_2$
c. $MgCO_3$
d. NH_4Cl

7. A solution, which contains only one of the following cations: Mg^{2+}, Pb^{2+}, or NH_4^+ is tested with the following reagents and the following results are obtained:

Reagent	Results
0.1 M Na_2SO_4	Precipitate
0.1 M NaI	precipitate
0.1 M $NaNO_3$	no precipitate

This cation is:

a. NH_4^+
b. Pb^{2+}
c. Mg^{2+}
d. Na^+

8. We want to separate the cations in an aqueous solution containing $Pb(NO_3)_2$ and $Ba(NO_3)_2$ by selective precipitation method. Preliminary tests give the results in Table1.

Table 1 : Selective precipitation of barium and lead ions

Cation	Test solution (anion)			
	NaCl (Cl^-)	Na_2SO_4 (SO_4^{2-})	NaOH (OH^-)	Na_2CO_3 (CO_3^{2-})
Pb^{2+}	White precipitate	White precipitate	Precipitate	Precipitate
Ba^{2+}	No reaction	No reaction	No reaction	Precipitate

Which of the four test solutions in table1 give some unexpected results?

a. NaCl
b. Na_2CO_3
c. NaOH
d. Na_2SO_4

9. When potassium iodide reagent is added to a neutral unknown solution a yellow precipitate forms immediately. What might the unknown solution be?

a. Silver (I) nitrate
b. Iron (III) nitrate
c. Lead (II) nitrate
d. Barium (II) nitrate

10. The correct Ksp expression for CaF_2 dissolving in water is?

a. $K_{sp} = [Ca^{2+}]^2 \times [2F^-]$
b. $K_{sp} = [Ca^{2+}] \times [2F^-]^2$
c. $K_{sp} = [Ca^{2+}] \times [F^-]$
d. $K_{sp} = [Ca^{2+}] \times [F^-]^2$

11. Which of the following arrangements of the solubility of $CaSO_4$, $Ca(OH)_2$, and CaF_2 is correct?

a. $CaSO_4 > Ca(OH)_2 > CaF_2$
b. $CaF_2 > Ca(OH)_2 > CaSO_4$
c. $CaSO_4 > CaF_2 > Ca(OH)_2$
d. $Ca(OH)_2 > CaF_2 > CaSO_4$

Salt	**Ksp**
CaF_2	1.5×10^{-11}
$CaSO_4$	7.1×10^{-5}
$Ca(OH)_2$	4.7×10^{-6}

12. What must the silver-ion concentration (in moles/litre) be in order for precipitation to just begin when 2 ml of silver ion is added to 2 ml of 5.0×10^{-4} M Na_2CO_3 solution? (K_{sp} = for Ag_2CO_3 is 8.5×10^{-12})

a. 4.1×10^{-9}
b. 1.6×10^{-8}
c. 6.4×10^{-5}
d. 1.3×10^{-4}

13. Two solutions of equal volumes are mixed one containing Ag^+ and the other Cl^-. If at the instant of mixing, $[Ag^+]$ is 10^{-3} M and $[Cl^-]$ is 10^{-3} M, which one of the following statements is true? (Ksp for AgCl is 1.8×10^{-13})

a. A precipitate forms because Q is less than Ksp.
b. A precipitate forms because Q is greater than Ksp.
c. No precipitate forms because Q is equal to Ksp.
d. No precipitate forms because Q is greater than Ksp

NOTE: Q stands for ion product and K_{sp} stands solubility product constant.

14. A solution contains Ag^+, Ba^{2+}, Fe^{3+} and K^+. What compounds (give correct formula for each compound) could be added, and in what order, to separate these ions from the mixture. What ion will remain in the solution at the end of the separation process?

Use this space to write answers for question 14.

What compound could be added?	Represent what you would see happening by a net chemical equation.
(a) 1st	
(b) 2nd	
(c) 3rd	
(d) 4th	

(e) Explain why would you follow the order of addition from 1st to 4th in order to separate the four ions from a mixture? (*Use the space below to write your explanation*).

15. (a) What is the difference between solubility product and ion product?
(b) Barium sulphate, which is opaque to X-rays, is used for the "barium meal" to enable X-ray pictures to be taken of the gut. Barium ions are very toxic; why is this not a problem here?
(c) Will the solubility of Barium sulphate in a solution of 0.25 M Na_2SO_4 be greater or lower than that in pure water? Explain. [*Use the backspace to write answers for this questions.*]

APPENDIX B

Final version of exemplary lesson materials
Teacher support materials (lesson 3)

Using solubility rules in the qualitative analysis of ionic compounds

1. Introduction

- Detectives in mystery novels often rush evidence from the crime scene to the laboratory for analysis. In this lesson, students will learn how to become a chemical detective. In the laboratory, there are six (6) *labels that have fallen off reagent bottles containing aqueous solutions of different chemicals. It is difficult to tell, which label belongs to which bottle.* Therefore, students will have to carry out *qualitative analysis* to determine the identity of chemical composition of unknown solutions (labels) on the basis of their reactivity with other solutions and by using solubility rules learned in lesson 2. Solutions are to be tested and their characteristic reactions noted. The analyses students will perform are based upon the data that each solution contains one ion, which will give a characteristic reaction by which the identity of the solution can be obtained
- The experimental set-up contains a sample of six (6) solutions, which are labelled A- F. An additional set of known solutions from the laboratory ledger is provided. The known solutions are identical to the unknown set. They are, however, not in the same order. No other chemical compounds have been provided and none of the samples are distilled water only.

2. Objectives of the lesson

It is expected that at the completion of this lesson students should be able to:

Work with small quantities of chemicals confidently; observe the reactions of common anions and cations in solution to simple chemical tests; and identify the ions present in an unknown solution based on the logical application of chemical tests and solubility rules.

3. Resource materials and further reading

United Republic of Tanzania (URT): Chemistry Syllabus for Secondary Schools, Form V-VI. Ministry of Education and Culture (MOEC), 1997. Topic 2.7, pp.37-39.

E.N. Ramsden (1994). A-level Chemistry 3rd Ed. England. Stanley Thornes Publishers Ltd. (pp. 273-277)

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4. Preparation

Prepare the following requirements for the experiment.

Apparatus

A4 reinforcement pocket paper (i.e. plastic reaction sheet, 1 per group), paper grid (see Tables 3.1 & 3.2, 1 per student), Small plastic pipettes (one for each solution), 250mL beaker (1 per group), 50 mL plastic beaker (2 per group), Rolls of toilet paper (2), Masking tape (4 pieces per group), Toilet soap (1piece), toothpick (1 packet).

Chemicals

- Photo film containers (ca. 50mL) labelled A, B, C, D, E, and F the following aqueous solutions: barium chloride, sodium sulphate, lead (II) nitrate, sodium hydroxide, silver nitrate, and sodium iodide. All solutions at the concentration of 0.1 mol / litre except 0.2 $molL^{-1}$ for silver nitrate solution.
- Distilled water (at least 250 ml per group). Use bottled water 'Kilimanjaro' if not available.
- All reagents containing the unknown solutions of ions for the experiment must be prepared and tried out before the lesson day to check if everything works well (*See solution preparation guide in Appendix* 2.2)

5. Safety

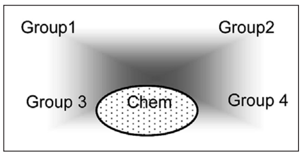
Unknown chemical may pose unexpected hazards. Wash your hands immediately upon contact with chemicals. Avoid breathing vapours from chemicals. Lead solutions are poisonous so are barium solutions. Silver nitrate causes stains on your skins and potassium dichromate is a strong oxidizing agent

6. Lesson plan and Timing (min)

Time	*Student activities*	*Teacher role*
15	Representatives of small groups present scheme to separate ions from a mixture of solutions as part of pre-lab exercise.	Let students present their answers of the pre-lab exercise. Explore students' alternative ideas/misconceptions.
25	Small groups perform chemical tests for known and unknown solutions, observe and record results.	Monitor group activities. Check student participation in the activities (e.g. mixing drops, recording).
40	Compare and analyze experimental results to identify unknowns A – F based on experimental results.	Visit groups and provide support or guide
25	Pairs of groups present their results, analysis and conclusion to the whole class.	Lead presentation and do appropriate timing. Note down emerging ideas for discussion from each presentation.
40	All students discuss presentations. Focus on differences of experimental results between groups and also in relation to their pre-lab exercise.	Focus student discussion by relating observed results to solubility rules and list of solutions. Provide correct identity of unknown solution to conclude the lesson.
05	Copy simulated problem for homework and note down assessment guidelines.	Assign simulated problem and talk on assessment guidelines.
10	Clean up work places and apparatus Return all apparatus and unused solutions	Make sure that all unused solutions and sheets are returned and all wastes are put in proper waste container.

7. Group work

Set framework for small group activities, for example, the number and roles of members (preferably 3 students per group), arrangement of chemicals, and duration of activity, recording data and important resources. See possible table or work bench arrangement on the right.



8. Start of lesson

Begin your lesson with students presenting proposed separation scheme to separate each of the four ions (Ag^+, Ba^{2+}, Mg^{2+}, and or K^+) from others as per pre-lab exercise sheet (Appendix 3.1). Explore and note any emerging students' alternative ideas for discussion. Give information to students on the purpose of the experiments in activity 1 and 2. Guide them through the activities.

Experiment 1

Several solutions are mixed together, two at a time, to determine which combinations produce a precipitate and, if so, the nature of the precipitate (Table 3.1). After all of the combinations are tried and the results recorded, the students are expected to be able to recognize the same chemicals in unlabeled containers of solutions A–F (Table 3.2).

- Let students use key to record observations as the one provided in lesson 2.

Solution of	$BaCl_2$	Na_2SO_4	$NaOH$	$Pb(NO_3)_2$	NaI	$AgNO_3$
$AgNO_3$						▨
NaI					▨	
$Pb(NO_3)_2$				▨		
$NaOH$			▨			
Na_2SO_4		▨				
$BaCl_2$	▨					

Observation Table 3.1: Reactivity grid of combinations of known aqueous solutions.

Experiment 2

Six aqueous solutions (A-F) are mixed, two at a time, reactions noted and studied to identify the ionic composition of each solution.

Solution of	A	B	C	D	E	F
F						▨
E					▨	
D				▨		
C			▨			
B		▨				
A	▨					

Observation Table 3.2: Reactivity grid of combinations of unknown aqueous solutions

9. Conclusion of lesson

Conclusion must be derived from the analysis and discussion of experimental results, and with the help of the solubility rules for ionic compounds in water. Expected identity of solutions is listed below.

Label	Solution Chemical name	Formula	Ions present	
			Cations	anions
A	Lead (II) nitrate	$Pb\ (NO_3)_2$	Pb^{2+}	NO_3^-
B	Barium chloride	$BaCl_2$	Ba^{2+}	Cl^-
C	Sodium hydroxide	$NaOH$	Na^+	OH^-
D	Silver(I) nitrate	$AgNO_3$	Ag^+	NO_3^-
E	Sodium sulphate	$Al_2(SO^4)_3$	Al^{3+}	SO_4^{2-}
F	Sodium iodide	NaI	Na^+	I^-

10. Assignment

Suggested question for group homework to consolidate lesson outcomes

After a successful completion of your advanced secondary education in chemistry you are invited to a written interview with the office of the Chief Chemist in Lake Zone, describe how you would proceed answering the following question:

Recently, fish in Lake Victoria began to die in large numbers. The lake is down the stream from copper mine, also known to contain some lead and silver ores. Copper (Cu^{2+}) and Lead (Pb^{2+}) ions are known to be lethal to fish. A sample of the mine effluent has been sent to the laboratory of the Chief Chemist for analysis. Devise a qualitative analysis scheme to identify (if either) of the above cations is present in water. Your qualitative analysis scheme should show which reagents you would use and what conclusions you could reach at each step. Where a reaction could occur, write a net ionic equation (with state symbols).

11. Teaching notes

Results

After adding reagents to the appropriate squares on plastic sheets, interactions between some combinations of ions will be observed. Not all combinations will produce a precipitate or will result in a colour change as evidence of chemical reactions. Table 3.3 shows expected results from the solution combinations. "I" for insoluble indicates where precipitates occurred, "s" for soluble indicates where precipitates did not occur, and "ss" for slightly soluble indicates where precipitates occurred just a little and not immediately. The colours: shown brown, cream and white show the precipitate that is formed.

12. Analysis and Discussion

With the help of solubility rules for ionic compounds, the list of solutions, and the observed interaction of solutions, guide students to identify the ionic composition for each of the six solutions (A-F). The identification process should start with the most identifiable precipitate and branches out from there. From the observation table the most *characteristic precipitate* is *the brown/ thick tan* of silver hydroxide. Since this precipitate is in the squares containing solution D and C, solution C and D must contain the silver ion and hydroxide ion sources. Further observations show that solution D also form precipitates

Table 3.3: Expected observation results

Solution of	A	B	C	D	E	F
F	i yellow	s	s	i cream	s	
E	i white	i white	s	s		s
D	s	i white	i brown		ss white	i cream
C	i white	s		i brown	s	s
B	i white		s	i white	i white	s
A		i white	I white	s	ss white	i yellow

with B, E (white) and F (cream) while C does not. Therefore D must contain the silver ion source and solution C the hydroxide. We now have two of the six chemical solutions identified.

The identification process can continue by identifying chemical species with the precipitates associated with hydroxide ion. Only lead (II) hydroxide is a possible precipitate and it occurs when C is combined with A. Thus, A contains lead ions. Lead iodide is a *characteristic yellow colour* and appears when solution A combines with solution F. Therefore it can deduce that iodide is in solution F. We now know all precipitates with iodide; we need a different solid to sort out the last two solutions. After looking through the solubility rules and precipitate colours, we note that barium makes *a white solid* when combined with sulphate. This pattern is noted when B is mixed with E hence solution B contains barium and solution E contains sulphate. We have now identified all species (see conclusion above) by deductive reasoning through identification of the precipitates by employing solubility rules and the list of possible reagents

Key Terms and Chemical Concepts

Qualitative analysis (QA): The process of determining the composition of a sample of matter by conducting chemical tests. QA is a technique used to separate and detect *cations and anions* in a sample of substance. QA tells what the compound is, but not how much is present.

Qualitative Techniques (QT) for inorganic analysis is used to identify cations and anions in aqueous solution by simple reactions, mostly involving the production of a precipitate, evolving a gas or a visual colour change.

要　約

この論文は，タンザニアのＡレベル中等学校教育へ試験的に導入されたマイクロスケール化学実験（MSCE）の評価を，参加した教員および生徒の視点に基づき報告するものである．効果を従来型の第13学年の溶解度と析出に関する授業と比較する事で調査した．異なる４校の４人の教員と，195人の生徒が参加し，２人の教員は88人の生徒に対しMSCEを用いて，残り２人の教員は107人の生徒に対し従来型の方法で授業を行った．評価は複数の独立した指標であるテストの成績，授業観察，聴き取り調査および質問表調査に基づいて行った．教員と生徒のMSCEに対する考えは肯定的であった．教員は新手法の導入を通じ能力向上を達成し，また省資源の実験を通じた生徒への支援について自覚的になった．同様に生徒も実験にとても興味を持ち，自分たちで実行可能な，他の生徒と協力し，教員と自由に意見交換可能なものと感じている．また生徒たちは小グループでの議論や振り返りを通じてより科学的な能力を獲得している．MSCEはＡレベル中等学校の化学教育で実行可能で生徒に効果的な学習を提供するものであると結論づけられる．

（訳：教員教育国際協力センター）