SMALL-SCALE CHEMISTRY FOR A HANDS-ON APPROACH TO CHEMISTRY PRACTICAL WORK IN SECONDARY SCHOOLS: EXPERIENCES FROM ETHIOPIA

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ABSTRACT

The purpose of this study was to investigate the possibility of using a small-scale chemistry (SSC) approach as a means of performing chemistry practical activities in Ethiopian secondary schools. A total of eight experiments from two topics, electrolysis and rate of reaction, in the Ethiopian grade 11 chemistry syllabus were modified into SSC for use with the MyLab Chemistry Kits (Northwest University, South Africa). The evaluation involved classroom testing of the SSC materials to investigate the effect of the approach compared to the regular teaching approach. Two comparable groups of Grade 11 science stream students (188 experimental; 195 control) and their chemistry teachers participated in the study. Triangulation procedures involving classroom observation of the use of the SSC approach in classrooms, student achievement tests (pre and post-test), questionnaires, and interviews were employed for data collection. Results showed that the SSC approach can increase students understanding of chemistry concepts. Furthermore, despite the presence of some challenges in operating the small-scale equipment, collecting quantitative data, and maintaining class discipline, the SSC approach was viewed by both teachers and students as cost and time saving, safer, easy to use and enjoyable. *[AJCE 4(3), Special Issue, May 2014]*

INTRODUCTION

Background

Practical work carried out by students themselves is an essential part of science education although critical views on its effectiveness also exist [1-2]. Many science educators and science education researchers believe that student practical work leads to better science learning. Hofstein and Mamlok-Naaman [3, p. 105], for example, stated that "laboratory experiences have been purported to promote central science education goals, including the enhancement of students' abilities; scientific practical skills and problem solving abilities; scientific 'habits of mind'; understanding of how science and scientists work; interest and motivation". Layton [4] argued that chemistry without practical work was seen as a body of factual information and general laws, which conveyed nothing of lasting power to the mind. In this paper the term 'practical work', as it is commonly used in the science education literature, refers to any type of science teaching and learning activity in which students, working either individually or in groups, interact with materials to observe and understand the natural world.

In line with the above arguments, the education and training policy of Ethiopia [5] declares that science should be taught in a practical manner. The policy discourages rote and memory learning. In principle, the Ethiopian secondary (grade 9-12) chemistry curriculum focuses at enabling students to solve real life problems, and become independent and helpful citizens. Accordingly, central to the teaching-learning process in the secondary chemistry curriculum is practical work geared towards mastery of scientific skills: process skills, manipulative skills and thinking skills. More specifically, after completion of their upper secondary chemistry syllabi students are expected to use scientific methods in solving problems; and demonstrate an understanding of experimental skills, knowledge of laboratory procedure and scientific enquiry skills including observing, inferring, predicting, comparing and contrasting, communicating, analysing, classifying, applying, theorizing, measuring; asking questions, developing hypotheses, performing and designing experiments, interpreting data, drawing conclusions, making generalizations and problem solving [6]. Although being good teaching ideals, as we shall see, in Ethiopia these expectations are hard to fulfil.

If implemented as intended, practical work in chemistry gives students opportunities to gain the above listed skills through scientific investigations and hands-on activities. Practical activities can also promote positive attitudes and provide students with opportunities to develop skills in cooperation and communication [7]. From a constructivist point of view, students need to be active participants in the learning process in constructing meaning and developing understanding [8]. In line with this, Bradley [9] and many others argued that practical work should involve active participation of students.

While practical work is considered essential in chemistry teaching, it is also associated with a number of burdens including high cost of equipment and chemicals, chemical hazard risk, and environmental pollution. Furthermore, practical work requires more time and the presence of qualified and experienced teachers and technical assistants. As a result, it is frequently missed from the real curriculum in schools around the world [9], especially where resources are scarce.

Though no extensive studies have been conducted on the situation of secondary science teaching in Ethiopia, the few available studies have demonstrated the lack of hands-on practical activities in schools. Bekalo and Welford [10], for example, reported that, for a number of reasons, secondary school students in the country were not getting science hands-on experiences as specified in the curriculum. Similar findings [11] had been reported in a study conducted to assess the overall quality of secondary science education in North Ethiopia (Tigray region) by a team of science educators in which one of the authors of this paper was a member. Amongst the reasons mentioned are: absence of laboratory room, lack of equipment and chemicals, shortage of time, large workload, absence of laboratory technical assistants, fear of chemical hazards, teachers feeling inadequately prepared, lack of laboratory manuals, lack of basic facilities such as water or electricity, and large class size. It can also be argued that the problem has been worsened by the recently observed fast- growing student population in the sciences[1] not being matched with resources.

Some of the challenges associated with chemistry practical work may be overcome through the use of a small-scale/microscale chemistry experimentation approach. In this study, the approach has been tried out on two chemistry topics in secondary school classrooms in Ethiopia, and the effects have been evaluated.

Small-scale chemistry

Small-scale chemistry (SSC) is chemistry carried out on a reduced scale using small quantities of chemicals and often, but not always, simple equipment [12] with a shift from glassware to plastic materials [14]. Sing et al. [13] reckon that at the lower end of the scale, solids and liquids of 25–100 milligrams and 100–200 microliters respectively may be used without compromising the quality and standard of the chemical applications in education and industry [13]. In our experience even a tenth of this may be suitable in many experiments. The terms *microscale* and *small-scale* are often used interchangeably and refer to a similar scale of chemistry [12]. In this paper, the term *small-scale chemistry* (SSC) is used.

[1]It is believed that the student population in the science streams of the secondary schools in Ethiopia has been increased abruptly since the implementation of the 70:30 policy. According to the policy which has been implemented as of 2008, 70% of the student enrolment in universities (and secondary schools alike) has to be in the natural science and technology related fields.

Reduction of waste production at the source was the main driving force behind the interest in SSC [12-13]. In the USA, for example, the National Microscale Chemistry Centre (NMCC) was established in 1993 to promote the use of microscale chemistry as a means of eliminating waste at the source [15]. Other motivations behind the move towards SSC include: the increasing cost of laboratory equipment and chemicals coupled with budget cuts, shortage of laboratory time [16], and the increasing application of safety legislation to educational institutions [12, 17].

The benefits of implementing SSC experimentation in chemistry teaching have been reported by many researchers [e.g. 12, 13, 18-30, 41]. Frequently mentioned benefits include: saves money and time, increases safety, is easy to use and environment friendly, instils ethics of resource conservation, enhances students' understanding of scientific concepts, maintains students' interest towards the subject, uniquely engage students in hands-on learning experiences, and experiments are perceived by students as easy and fun. Bradley [21] argues that the SSC approach can help address many of the challenges that teachers face when planning practical work including shortage of equipment and chemicals, lack of laboratory space, lack of laboratory assistants, shortage of time, and lack of confidence by teachers.

A few limitations of the SSC approach are also reported. Experiments which involve heating, the use of organic solvents or concentrated acids are unsuitable for the approach in which most of the equipment is made of plastic materials [22]. Nowadays, there are alternatives in which some glass equipment are included in the kits; the MyLab small-scale chemistry kit is one such example (31). Difficulties in getting accurate results for quantitative experiments and problems in handling some of the apparatuses are also reported as limitations [21, 30, 32] and are supported by our own experiences.

SSC experiences in Africa

Although small-scale techniques have been introduced in Egypt as early as 1924 [33], little progress was made in the rest of Africa for almost seventy years. It was only in the 1990s that such techniques were successfully introduced in South Africa by the Research and Development in Mathematics, Science and Technology Education (RADMASTE) centre, University of Witwatersrand, South Africa. The RADMASTE kits introduced with the aim of addressing the problems of science practical work in schools of disadvantaged communities mainly due to the efforts of John Bradley [34]. Since then, a number of African countries, being aware of the potential benefits, have implemented the new approach of science practical work in their respective education systems, and some others have been on the way [35]. Other kits, also of South African origin, are the MyLab small-scale science/chemistry kits which were designed in 2001 by Corrie du Toit, and his colleague, Marié du Toit of the Faculty of Natural Sciences, North-West University. These have also been successfully implemented in a number of South African schools and beyond [31].

A few studies have documented the effectiveness of the SSC approach in the African contexts [e.g. 24, 36-41, 52]. Bradley and Vermaak [52] reported knowledge gains and positive attitudes in a study on South African secondary school students after their involvement in microscale practical work. Also in teacher training institutions in South Africa this approach has been proven beneficial [36]. Madeira [40] studied the influence of microscale chemistry experimentation in Mozambican junior secondary schools and reported significant gains in chemistry achievement. Similarly, the impact of microscale on students' understanding of concepts and their attitudes towards the approach has been positively reported by Mafumiko [37, 38] in Tanzania. Cameroon, Uganda, and Kenya are other examples within Africa where SSC has received very positive response from both teachers and students [43]. Not surprisingly, UNESCO [35] has reported a strong demand for introducing the SSC approach from countries like Sudan, Ethiopia, Tanzania and Gambia.

A positive feedback from students, teachers and school principals has been reported from a pilot introduction of SSC in two Ethiopian secondary schools [42]. No other empirical studies are, to our knowledge, reported so far on SSC experiences in the Ethiopian school context. This study, therefore, contributes towards filling the gap and thereby informing concerned parties regarding the strengths and limitations of the approach.

PURPOSE OF THE STUDY

The main purpose of the study was to explore the possibility of using the SSC approach as a means of performing chemistry hands-on practical activities in Ethiopian secondary schools, and thereby reducing the need for costly equipment and expensive laboratories. Specifically, the study aimed at evaluating the effectiveness of the SSC approach in supporting classroom implementation of chemistry hands-on practical work against the teaching approaches normally in use; assessing students' and teachers' perceptions towards the SSC approach; and comparing the chemistry performance of students taught using the SSC experimentation approach with those taught using the 'traditional' teaching approaches. The study tried to answer the following questions:

i. What were the experiences when implementing hands-on chemistry practical work through the SSC approach in secondary school classrooms in Mekelle, Ethiopia?
ii. What were the 'students' and 'teachers' reactions to the SSC experimentation approach?

iii. What were the differences in the chemistry test performance of the two groups of students in the small-scale approach (experimental group) and the approaches normally used in chemistry classes (control group)?

METHODOLOGY OF THE STUDY

Research design

The procedure of the overall study, in which this paper is one part, consisted of three phases: The first was focused on front-end analysis (review of related literature and context analysis); the second involved development of SSC experimentation (acquisition of SSC kits and chemicals, and preparation of SSC laboratory manuals) based on the Ethiopian secondary chemistry syllabus; and the third evaluated the effectiveness of the SSC approach in some selected Ethiopian secondary chemistry classrooms. This paper focuses mainly on the latter phase in which a quasi-experimental design was used. The quasi-experimental design is commonly used in educational research when participants cannot be randomly selected and assigned to experimental and control groups [43, 44]. Consistent with this type of research design, in this study triangulation procedures involving chemistry concept understanding test, observation of the use of the SSC approach in actual classrooms by teachers and students, interviews and questionnaires, have been used to collect data.

Research participants

Participants consisted of 383 grade 11 (average age 17 years) science stream students from two selected governmental secondary schools (experimental and control schools): 188 of the students (88 males and 100 females) came from four intact classes in the experimental school while 195 (91 males and 94 females) came from four intact classes in the control school. Both schools are located in the same city (Mekelle, North Ethiopia) and have more or less the same number of student and teacher population. Schools were selected based on purposive sampling (43) considering the willingness of the chemistry teachers and school principals; matching of the topic of investigation with the teachers' scheme of work; and presence of reasonable number of grade 11 science students in the schools. Both schools were interested in implementing the intervention; but were assigned as experimental and control schools using the lottery method.

The control school demanded to have the experiments afterwards if they were to participate, and were promised so. Participating teachers were those who were teaching the study classes. Thus, six teachers (four experimental and two control) participated in the study. All of the teachers had a Bachelor of Education degree in chemistry teaching[2] while one (teaching in the control class) had attained Master of Science degree in the same field. All of the teachers had 10-15 years of experience in teaching chemistry at the upper secondary level.

Implementation of the study

Two topics – electrolysis and rate of reaction –were selected from the Ethiopian grade 11 chemistry syllabus for the purpose of the study. Fourteen sets of MyLab small-scale chemistry kits were acquired from South Africa (Mylab project, Northwest University). The experiments included in the study topics were modified to the SSC approach for use with the kits. A two-days training workshop on the SSC approach was offered to the four experimental school teachers and a lecturer of chemistry from Mekelle University (Ethiopia). No such training was given to the

[2] Three years of in-service chemistry teacher education in Ethiopian teacher training institutions results in the award of 'bachelor of education degree in chemistry teaching' and qualifies for a lower secondary (grades 9-10) chemistry teaching

control school teachers; only a brief orientation regarding the study was offered just before the start of the implementation.

During the classroom implementation of the study, the experimental class teachers were required to implement the SSC experimentation approach in teaching the study topics i.e. they were required to conduct their lessons in a hands-on manner using the provided kits, manuals and other materials. Accordingly, each of the experimental classes carried out a total of eight SSC hands-on experiments during the implementation period. Students carried out the experiments in groups of 4-5, where a MyLab kit and two copies of the developed manuals, and other supplementary materials were provided for each group. In the curriculum, chemistry is given four periods (40 minutes each) per week. The experimental class teachers used two periods for teaching concepts and two periods for conducting the small-scale hands-on experiments. On the other hand, the control class teachers were requested to conduct their lessons on similar topics using their regular teaching methods. Both the experimental and control group teachers conducted the study lessons for over one month.

Data collection

Data were collected through four instruments: chemistry concept test, student questionnaire, individual teacher interview, and classroom observation. Chemistry pre-test and post-test consisting of fifteen multiple choice items and four short answer items were developed by the researchers. The test items were mainly composed of knowledge, comprehension and application questions and covered the two study topics: electrolysis and rate of reaction. Prior to administration, the contents of the test were validated by one university lecturer and two experienced upper secondary school chemistry teachers. The test was also pilot-tested in one upper secondary school of the same grade level as students in the study school and improvements were made on the basis of the feedback. The internal consistency of the multiple choice test items was computed using Kuder-Richardson KR-21 and a reliability coefficient of 0.74 was obtained. For the short answer items an inter-ratter reliability coefficient of 0.94 was obtained. The pre-test was administered to gauge the prior knowledge of students on the topics; while the post-test to measure their learning gains. Similar questions were administered both in the pre-test and post-test. Samples of the questions are given in appendix 1.

Data regarding student experiences and opinions about the SSC based lessons were collected using a semi-structured questionnaire adapted from one used by Mafumiko (38) in similar studies. Students of the experimental classes filled the questionnaire at the end of the classroom implementation of SSC based lessons. The questionnaire consisted of a total of 17 items: 14 close-ended items and 3 open-ended items. A scale of 1 to 5 was provided for each close-ended statement item (1=strongly disagree, 2= disagree, 3=neutral, 4= agree & 5= strongly agree) for the students to indicate their response about their perceptions in relation to SSC based lessons. The open-ended questions also focused on students opinions/perceptions towards the SSC approach; differences between the SSC approach and the usual/traditional teaching approaches normally used by teachers; and problems encountered with the SSC approach. The internal consistency of the questionnaire was estimated (using SPSS version 16.0 software) based on the close-ended component of the questionnaire and a reliability coefficient of 0.83 was obtained.

The feasibility of using the SSC approach in actual classrooms was evaluated by conducting individual interviews with the experimental class teachers. The interviews were conducted at the end of the classroom implementation of the SSC based lessons and were focused on the helpfulness of the two-day training workshop on SSC offered to the teachers; the applicability of the SSC experimentation in actual lessons; how the SSC experimentation helped the teachers to instruct in a student-centered manner; and what problems were encountered during class room implementation of the SSC experimentation with students. All interviews were transcribed and the informants anonymized.

A 29-item classroom observation checklist adapted from previous similar studies (38, 45, 46) was implemented to collect classroom observational data. In the experimental classes, classroom observations were made aimed at observing how teachers and students were implementing the SSC experimentation approach in teaching the study topics using the provided materials (student worksheet, teachers' guide and small-scale chemistry kits). In the control classes the classroom observations aimed at observing how teachers were implementing the same topics in their lessons using regular teaching approaches. The same classroom observation checklist was used in both the experimental and control classes. However, in the control classes, only items applicable to the lessons were considered. In addition to this, to get insight into the overall situation of the classrooms, open notes were taken during the lesson observation.

Data analysis

An independent samples t-test was conducted to examine whether there was a significant difference between the experimental and control group students in relation to their understanding of chemistry concepts with $P < 0.05$ being considered as significant. Data from the close-ended questions (Likert-type items) of the student questionnaire were analyzed by computing the means, standard deviations, and the percentage of students who rated as "4=agree" or "5=strongly agree" for each of the items. Data from the open-ended questions of the student questionnaire, individual teacher interview and classroom observation were reported qualitatively.

Informed consent

The project was both staged and undertaken logistically through the schools. Informed consents were obtained from local authorities, school principals, teachers and students themselves after information on the purpose of the project, as a trial introduction of small-scale chemistry with an evaluation and as part of a PhD thesis that should be made public afterwards. Participants were informed that the evaluation consisted of student questionnaires and chemistry tests, teacher interviews and classroom observation during lessons. Furthermore, participating students and teachers were informed that their class and group activities as well as individual interviews would be photographed and tape recorded. Due to the little sensitivity of the project and its evaluation, consents were made in an oral form. A letter of support was also produced from the education bureau of the Tigray region. The teachers and students participated voluntarily and were informed that they could withdraw from the project any time. The identity of the participants has been made anonymous throughout the project.

RESULTS AND DISCUSSIONS

Results from context analysis (Overview of the situation of secondary schools)

The education system in Ethiopia consists of eight years of primary education, divided into two 4-year cycles, and four years of secondary education, divided into two 2-year cycles (lower secondary education: grades 9–10, and upper secondary education: grades 11–12). The Education Statistics Annual Abstract of the Bureau of Education [47] of the Tigray region, where the study was conducted, shows that there were a total of 24 secondary schools in the Mekelle city; 11 upper secondary, 13 lower secondary; 8 governmental, 16 private schools. In total there were nearly 22 000 students (almost 10,000 males and 12,000 females) and nearly 730 teachers (almost 600 males and 130 females).

According to the Education policy of Ethiopia, lower secondary school teachers are supposed to have a first (bachelor) degree, while upper secondary are supposed to have a second (masters) degree in the fields they teach. More than 90% of the teachers were first degree holders, and only very few of them attained their second degree. This shows that most of the upper secondary teachers had no sufficient qualifications as required by the policy. With respect to material resources, the problem seems even more severe: out of the 24 secondary schools, for example, two had no access to running water, four had no library, one had no laboratory room at all while five have only a shared one for the three science subjects, and 16 had no source of income of their own to spend on materials [47].

The results from the observational visit to the eight governmental schools in Mekelle city in the Tigray region (including the two which were selected for the SSC try-out) show that chemistry laboratories were at a very poor status. Most of the laboratory rooms were not to the standard (or not built for laboratory purpose) and lacked even the most basic facilities like running water, source of electricity; working tables, sinks, hoods, etc.. In some cases the rooms had broken windows, roofs, doors etc., and as a result were not secure places in which to keep materials. The rooms also lacked the required equipment and chemicals. In some of the older schools a considerable number of equipment and chemicals were present; however these have been kept idle for years. Consequently most of the equipment were broken and parts missing.

For the chemicals, many had expired and were clearly decomposed, stoppers were broken and labels had fallen off. These chemicals were therefore inadequate for teaching and in addition caused a waste problem. The teachers lacked the required qualification and skills, were overloaded with a number of assignments and, unsurprisingly, did not feel in a position to solve/handle the lab problems, and, even less, to explore innovative ways (e.g. low-cost and time saving approaches) of implementing chemistry hands-on activities in their classes. Administrators gave little or no attention to the complex problems associated with laboratory activities. In conclusion, in these schools, the possibilities for hands-on student experiences were very minimal. The teaching was dominated by the traditional ‘chalk and talk approach’ which is characterized by teacher and textbook domination, lectures, note giving, memorization, and lack of practical work; though the policy requires otherwise. The information obtained from teachers confirmed our observation.

During a discussion a teacher for example pointed out the problem saying;

Firstly, I do not believe I have proper training to implement chemistry practical work in my classes, secondly, I do not have sufficient time to engage my students in chemistry practical work, I am so loaded and just run for coverage only. In addition to this, the laboratory is not equipped with the required materials; no trainings are given to us on laboratory skills. In general, there is lack of attention.

In theory, the situation described only holds for Mekelle city in the Tigray region. However, there is no reason to believe that similar characteristics are not applicable in the rest of the country. Our observations and findings agree with reports from other studies in Ethiopia [e.g. 10, 48] and abroad [9, 49, 50]. Zymelman [49] and Lewin [50] reported that science education in developing countries is, amongst others, characterized by absence of hands-on practical experiences and poor understanding of scientific methods. Cost, safety, waste disposal and teacher training issues were identified as the main reasons for the lack of science practicals [9].

Results from development process of the SSC experiments

The second phase of our study involved the development and adaptation of SSC experimentation for Ethiopian classrooms. Fourteen MyLab small-scale chemistry kits (Figure 1) and related teaching materials were acquired from the MyLab project of Northwest University, South Africa. The MyLab kits were selected as the authors have experienced their versatility in different school settings. The kits mirror the traditional chemistry lab, but in a miniature format. They are self-contained by including chemicals and equipment for the majority of experiments mentioned in the syllabi for secondary schools and through the first year general chemistry course at university level.

Figure 1 MyLab small-scale chemistry kit set

Analysis of the Ethiopian secondary chemistry [6] was carried out to examine the topics and nature of practical activities included. It was found that no less than 80 experiments were mandatory. These required at least 66 large-scale apparatuses (like digital pH meters, digital balances, different flasks etc.) and 85 different chemicals (see appendix 4) which is unrealistic given the existing Ethiopian school context. Each of these 'large-scale' experiments were studied and found to be adaptable to the SSC approach.

Based on the analysis and practical considerations, eight experiments from the two grade 11 chemistry topics (electrolysis and reaction rate) were selected[3] and adapted into the small-scale approach for use with the MyLab kits (Table 1). Drafts of student worksheets and teachers' guide laboratory manuals were prepared using MyLab grade small-scale chemistry manuals [51] as main sources. The experiments were, then, self-tried repeatedly by one of the authors at the chemistry laboratory of Department of chemistry, Mekelle University (Ethiopia), and improvements were made.

Table .1 the developed SSC experiments

Experiment 1: electrical conductivity of ionic compounds

Experiment 2: effect of an electric current on water

Experiment 3: effect of an electric current on an aqueous sodium iodide solution

Experiment 4: effect of temperature on reaction rate

Experiment 5: effect of concentration on reaction rate

Experiment 6: effect of surface area on reaction rate

Experiment 7: effect of nature of reactants on the reaction rate

Experiment 8: effect of catalyst on reaction rate

A two-day training on small-scale chemistry was provided to four grade 11 chemistry teachers of the experimental school and instructed by one of the authors. During the training, teachers performed each of the small-scale experiments by themselves with a minimal help from the instructor and gave a number of suggestions which were used to improve the final versions of the teachers' guide and student worksheet materials thereby also developing an ownership to

[3] Only experiments which were offered in the second semester (as in the syllabus) were considered. Experiments which need special equipment, not available in the MyLab kit, and those which need excessive heating were excluded. Accordingly, the experiments in the two topics (rate of reaction and electrolysis) were found suitable.

experiments that were to be undertaken in the classrooms. See appendix 2, and 3 respectively for samples of the materials. Descriptions of two of the developed SSC experiments (experiments 1 and 4) are presented here for the sake of illustration.

Experiment 1: Electrical conductivity of ionic compounds

The objective of this experiment was to test the electrical conductivity of the aqueous solutions of some common ionic compounds. The experiment was conducted using sodium chloride, copper sulphate, calcium chloride, and sodium carbonate. The apparatus required for the traditional set-up were; 9-volt battery, 6-watt bulb with a bulb holder, conducting wires, carbon rods, 250-mL beaker, spatula and stirrer. In the small-scale set-up MYLAB apparatus stand was used to fix the required apparatus (including the battery, battery connection, the electrodes, and the water bowl). The water bowl replaced the 250 mL beaker, and the light emitting diode (LED) replaced the 6-watt bulb. Light emitted from the LED was used as an indicator of the conductivity of the aqueous solution and the intensity (brightness) as an indicator of the strength as well as the degree of dissociation of the electrolyte (salt) used (Figure 2).

Obviously with the four ionic solutions a bright light was emitted from the LED. Similar tests carried with table sugar failed to give glowing of the LED; only a faint light was observed probably due to the presence of some ionic impurities.

Unlike the traditional set-up which needs some additional materials to support the bulb and the two electrodes, in the small-scale setup the LED is permanently fixed on to the Mylab stand, the electrodes are easily supported by the two multi-purpose holes which exist in the stand. This makes the setup easy to use. The traditional set-up, as indicated in the student textbook [6], does not specify the amount of the compound to be used in preparing the aqueous solution, which may result in more waste of chemicals as students may use more than required. However, in the small-scale set-up, 4 micro-spatulas of each salt were sufficient to prepare the required solution. The time needed to perform the experiment was very short (not more than 40 minutes overall). The main reason for this saving in time was due to the fact that all apparatuses and chemicals were at hand in one kit.

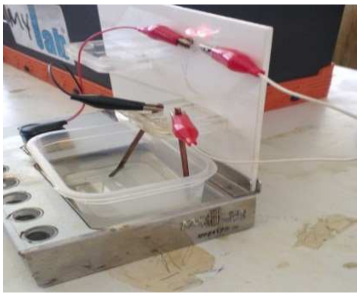

Figure 2. Small-scale setup (MyLab) for electrical conductivity test of ionic solutions

Experiment 4: Effect of temperature on reaction rate

The objective of this experiment was to study the effect of temperature on the rate of reaction between zinc and dilute hydrochloric acid (HCl). This was undertaken by using the specific gas units in the kits (in water baths of different temperature) and by measuring the volume of gas developed through downward displacement of water in a test tube. Two temperature conditions were used; one around 80^0C; and another around 0^0C, using ice water, which was replaced by room temperature water (Figure 3). As these reactions were run in parallel, the difference in the rate of the two reactions was easily observed.

Figure 3. Effect of temperature on rate of reaction between dilute HCl and zinc

The experimental setup of this experiment could be a bit challenging for both inexperienced students and teachers. However, after some trials, it was hoped, they would manage. Getting ice in schools could also be a problem and the experiment was later changed so that the water bath held room temperature.

Results from classroom observation (classroom observation checklist)

Observation in experimental classes

Two lessons were observed from each of the four experimental classes. The results in Table 2 show that almost all of the SSC based practical lessons were implemented successfully as per the criterion indicated in the observation checklist. Teachers made all preparations in advance including grouping and sitting arrangements of students; and making the SSC kits, student worksheets, and other supplementary materials ready for use. Teachers started the first experiment by forming small-groups of 4-5 students in which members shared roles (e.g. chairperson, secretary) among each other. Following the instructions given in the teachers' guide, all teachers introduced the practical lessons/experiments by clarifying the purpose of the experiments; and explaining how students obtain materials from the kits, and how to use them. They also strongly advised their students to read safety instructions carefully.

When it comes to the body of the lessons, the results show that teachers demonstrated the experiments to their students at the beginning of the experiment and in the course of the experiment when requested by students; and were moving around groups to give further help when students were engaged in the practical activities. During the activities, student-student and student-teacher interactions were very high, a situation, we believe, is not often encountered in most classrooms in Ethiopia. This could be due to the assignment of a separate SSC kit and a student worksheet to each group.

Working in small groups and performing experiments by themselves for the first time had also contributed to the high motivation and participation observed in all students. Most students demonstrated ability in using the apparatus and materials, and eagerly tried to follow the instruction provided in the student worksheets. Occasionally, when questions were asked, teachers were observed giving short presentations to the whole class. Their approach was friendly, and both they and their students were smiling, signs of their motivation and happiness of their involvement in the SSC based hands-on activities.

Table 2 results of classroom observation of the experimental classes

	Criterion to be observed	experimental class lessons observed							
		ET1		ET2		ET3		ET4	
	Introduction to the lesson	L1	L2	L1	L2	L1	L2	L1	L2
1.	Teacher relates the lesson to previous learning/future activities	+	+	+	+	+	+	+	±
2.	Teacher groups students for experimental work	+	+	+	+	+	+	+	+
3.	Teacher introduces by an activity (e.g. pre-lab exercise)	±	±	±	±	±	±	+	+
4.	Teacher makes connection between pre-lab activity and current lesson activities (if applicable)	±	±	±	±	±	±	+	+
5.	Teacher explains clearly the purpose of student practical	+	±	+	+	±	+	±	+
6.	Teacher explains how students will obtain materials	+	+	+	+	+	+	+	+
7.	Teacher emphasizes students to read carefully safety instructions	+	+	+	+	+	±	±	+
8.	Teacher asks group members to assign and share roles during activities (e.g. chairperson, secretary)	+	+	+	+	+	+	+	+
	Body of the lesson								
9.	Teacher explains how to use materials and equipment	+	+	+	+	+	+	+	+
10.	Teacher demonstrates experiments to students	+	+	+	+	+	+	+	+
11.	Students actively participate in doing hands-on activities	+	+	+	+	+	+	+	+
12.	Teacher moves around groups to insure experimental set-up and safety	+	+	+	+	+	+	+	+
13.	Students use information from the student worksheet	±	±	+	+	±	+	±	+
14.	Students demonstrate ability in working with apparatus and materials	+	+	+	+	+	+	+	+
15.	Students work cooperatively in small groups	+	+	+	+	+	+	+	+
16.	Teacher circulates among groups asking/answering questions	+	+	+	+	+	+	+	+
17.	Students seek help from the teacher during activities	+	+	+	+	+	+	+	+
18.	Students discuss their experimental activities in the small groups	±	+	+	+	±	+	+	+
19.	Students show interest in the experiments they are doing	+	+	+	+	+	+	+	+
20.	Groups present observations to the whole class	±	±	±	+	±	+	+	+
21.	Teacher and the students discuss the activities as a whole class	±	±	±	+	±	+	±	±
22.	Teacher makes short presentation at different times during the activities to help students grasp major concepts	+	+	+	+	+	+	+	±
23.	Teacher effectively manages timing of different activities	±	±	+	+	+	+	+	-
	Conclusion of the lesson								
24.	Teacher, together with students draws conclusions from the experiment	±	±	±	±	±	±	±	+
25.	Teacher discusses with the students their procedures and results	+	±	+	±	±	±	±	+
26.	Teacher guides students to understand differences in their results	+	±	+	+	+	±	+	+
27.	Teacher helps students to relate the activity with theory	+	±	+	+	+	±	+	+
28.	Teacher summarizes the main concepts learned from the activities	±	±	±	+	+	±	±	±
29.	Teacher checks learning of students (e.g. by oral questions, class discussions, homework questions)	±	±	±	±	±	±	±	-

Note: plus (+) means the activity was observed, minus (-) means the activity was not observed and plus/minus (±) the activity was partially observed. ET1, ET2, ET3 and ET4 stand for experimental class teacher 1, 2, 3, and 4 respectively. L1 and L2 stand for lesson 1 and 2 respectively.

Some limitations were also observed during the practical lessons. Due to the high student' participation in the experiments and group discussions, it seemed that, teachers lost control of time for other parts of the lesson like encouraging small-groups to give presentations to the whole class; making students to compare their results; drawing conclusions and summarizing the concepts learned from the experiments; and in checking student learning. However, given the lack of practical experience in handling active classes, this is not unexpected. The teachers should also know that experienced lab teachers encounter this "lack of control", but that they regard most of the buzzing as positive. "Real" problems, such as for example time management will, nevertheless, be handled better as both teachers and students engage in doing more hands-on activities.

Observation in control classes

In the control classes only four lessons were observed i.e. one observation in each control class. The results in Table 3 show that, while introducing their lessons, teachers tried either to define the concepts directly or ask oral questions about the topic to students. They also tried to relate their lessons with previous lessons, and to clarify lesson objectives. While presenting the main body of the lesson, the main tasks of the teachers were lecturing and writing notes on the black board and the main tasks of students were listening and copying the notes. Teachers were observed circulating around the class to insure 'disciple'. No hands-on practical activities were offered to students and their participation was limited to answering orally asked questions in between the lectures and written questions given in the form of class work at the end of the lecture. In general, the climate in the classrooms was passive. Because teachers were running the lessons at their own pace, they were good at managing and saving time for activities like checking student learning and summarizing the main points of the lesson.

Table 3 results of classroom observation of the control classes

Curriculum profile	Control class lesson observed			
	CT1		CT2	
Introduction to the lesson	L1	L2	L1	L2
1. Teacher relates the lesson to previous learning/future activities (e.g. checking home work)	±	+	±	+
2. Teacher organizes students for group activities	-	-	-	-
3. Teacher introduces the lesson by an activity	±	-	-	±
4. Teacher clearly explains objectives of the lesson	±	+	±	-
5. Teacher asks group members to share responsibilities during activities	-	-	-	-
Body of the lesson				
6. Teacher demonstrates experiments to students	-	-	-	-
7. Students actively participate in doing experiments / hands-on activities	-	-	-	-
8. Students work cooperatively in small groups	-	-	-	-
9. Teacher circulates among students/groups asking/answering questions	+	+	±	+
10. Students seek help from the teacher during activities	-	±	-	-
11. Students discuss their activities (exercises) in small groups	±	±	-	-
12. Teacher makes short presentation at different times during the activities to help students grasp major concepts	-	-	-	±
13. Teacher and the students discuss the activities (exercises) as a whole class	-	+	+	+
14. Teacher effectively manages timing of different activities	±	±	±	±
Conclusion of the lesson				
15. Teacher, together with students draws conclusions from the activity/ experiment	-	-	±	±
16. Teacher helps students to relate the conclusion of activity with theory	-	-	±	±
17. Teacher summarizes the main concepts learned from the activities	±	±	-	±
18. Teacher checks learning of students (e.g. by oral questions, class discussions, homework questions)	±	+	±	+

Note: CT1=control class teacher 1 and CT2= control class teacher 2

Comparison of the experimental and control classes

In general, the results of the experimental and control classes showed significant differences in the types of classroom activities, student-student and student-teacher interactions, and teaching styles. In the experimental classes students were active participants; using the opportunity to carry out a variety of hands-on activities by themselves, discuss in their groups and to interact with their teachers. On the other hand, in the control classes the information flow was one-directional. Thus, the classes were typically teacher-centered.

Thus, from the results of the classroom observation, it is possible to conclude that apart from the obvious benefit to implement hands-on chemistry experiments, this approach also promoted active learning. The results are consistent with the findings of Mafumiko [37-38] from Tanzania. Just like us, he observed that this approach, as fringe benefit, promoted active learning.

The impact of the SSC approach on students' understanding of chemistry concepts (results of pre-test and post-test)

To examine whether there was a significant difference between experimental and control class students in their academic performance in relation to understanding chemistry concepts, pre- and post-tests were administered to both groups. Data obtained were analysed using the SPSS (statistical package for social sciences) version 16.0 software. Comparison of the pre-test scores of the two groups by an independent t-test (Tables 4 and 5) revealed the absence of a statistically significant difference in the academic performances of the two groups: experimental group (mean = 7.97, standard deviation = 3.29), control group (mean = 7.82, standard deviation = 3.56); and the t-value is equal to 0.421 which was not significant at $P<0.05$.

Table 4 : comparison of the pre-test scores for experimental and control classes (group statistics)

	The group to which the respondent belongs	N	Mean	Std. Deviation	Std. Error Mean
Pretest result	Experimental	188	7.97	3.287	.240
	Control	195	7.82	3.561	.255

Table 5 : comparison of the pre-test scores for experimental and control groups (Independent Samples Test)

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Diff.	Std. Error Difference	Lower	Upper
Pretest result	Equal variances assumed	.079	.779	.421	381	.674	.148	.351	-.542	.837
	Equal variances not assumed			.422	380.2	.674	.148	.350	-.541	.836

Tables 6 and 7 below show a comparison of the post-test scores for the experimental and control groups in the chemistry concept understanding test. The test scores revealed the presence of a statistically significant difference between the academic performance of the two groups: experimental group (mean=13.37, standard deviation = 4.52), control group (mean = 9.49, standard deviation = 4.11); and the t-value is equal to 8.51 which was significant at $P<0.05$. The mean score of the experimental group was significantly higher than that of the control group. The findings show that the SSC hands-on practical activities could contribute to enhance students' understanding of chemistry concepts. The findings are in agreement with the results obtained from classroom observation, and teachers' and students' evaluations. Furthermore, the findings are in line with the findings of other researchers (e.g. 24, 30, 32, 37, 38, 40, 52, 53) who demonstrated that the small-scale/microscale approach can enhance students' understanding of chemistry concepts; and increase their interest and motivation towards the subject.

Table 6: comparison of the post-test scores for experimental and control groups (group statistics)

	The group to which the respondent belongs	N	Mean	Std. Deviation	Std. Error Mean
Post-test result out of 25 (total)	Experimental	172	13.37	4.520	.345
	Control	185	9.49	4.107	.302

Table 7: comparison of the pre-test scores for experimental and control groups (Independent Samples Test)

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Postest result	Equal variances assumed	2.106	.148	8.509	355	.000	3.886	.457	2.988	4.784
	Equal variances not assumed			8.479	345.23	.000	3.886	.458	2.984	4.787

Students' opinions about the SSC approach

Students' perceptions towards the SSC hands-on activities (close-ended questions)

The close-ended questions were administered to estimate the perception of students towards the SSC approach of performing chemistry hands-on activities. This part of the questionnaire consisted of 14 Likert-type items with a scale of 1 to 5 where "1=strongly disagree", "2=disagree", "3=neutral", "4=agree", and "5=strongly agree". The internal consistency of the items was estimated to be 0.84 (Cronbach's alpha, α=0.84). Data was analyzed by computing the means, standard deviations, and the percentage of students who rated as "4=agree'' or "5=strongly agree" for each of the Likert-type items. The results are summarized in Table 3.4 below

Table 8: Students' perceptions towards the SSC hands-on activities

Did you feel that the small-scale chemistry practical activities:	N	Ave	Stand. Dev.	% of A/SA
1. Were linked into other parts of chemistry	144	4.3	0.81	88
2. Helped you understand more about electrical conductivity of solutions of different compounds, electrolysis and rate of reaction	146	4.7	0.58	97
3. Made you feel like learning more about the subject	146	4.5	0.67	94
4. Helped you prepare for other topics in the text (syllabus)	145	4.4	0.84	88
5. Clarified some of the concepts that you have difficulties with	145	4.4	0.80	88
6. Made you enjoy your chemistry classes	146	4.5	0.75	89
7. Made your head think	145	4,6	0.69	96
8. Have given you confidence to carryout experiments by yourself	145	4.7	0.63	97
9. Provided you with opportunity to use materials and equipment	146	4.7	0.61	96
10. Made you feel working like a chemist	145	4.4	0.86	87
11. Made you actively participate in the lesson	146	4.6	0.69	95
12. Increased your cooperation and sharing ideas with fellow students	145	4.5	0.76	92
13. Made you feel very responsible about safety and environment	145	4,5	0,75	94
14. Exposed you to an easier way of doing experiments	143	4,6	0,55	97

Note: N: number of respondents per item; Ave: average score per item; %A/AS: percentage of students who rated as Agree or Strongly Agree.

As can be seen from the Table 8 about 146 students filled this part of the questionnaire. The mean scores of the items ranged from 4.3 and 4.7 and the overall mean was about 4.5. In general, the very high mean scores with small standard deviations show that the students' opinions about the SSC approach were highly positive. These findings are supported by many other researchers in similar studies [30, 37, 38, 52-57].

The strong positive perceptions were also reflected in the high ratings of each of the items. Most students indicated that performing the SSC hands-on activities by themselves enhanced their understanding of chemistry concepts: 97% believe (agree or strongly agree) that the activities helped them understand more about the topics (electrolysis and rate of reaction); 88% perceive that the activities helped them clarify some of the concepts that they had difficulties with; and 88% felt that the activities prepare them for other topics in the syllabus. In addition to this, students believed that the SSC practical activities made them feel like learning more about chemistry (94%), enjoy chemistry as a subject (89%), and feel like a chemist (87%). Furthermore, most students indicated that the SSC practical activities not only helped them enhance cooperation with their fellow students (92%) and made them actively participate in the practical lessons (95%) but also provided them with the opportunity to use and manipulate materials and equipment (96%). This is to be expected as students were performing the hands-on activities by themselves in small groups. Another result worth reporting was the great confidence students got as a result of exposure to SSC approach; 97% of them indicated that the SSC hands-on activities gave them confidence to carry out experiments by themselves.

Students' opinions about the SSC hands-on activities (open ended questions)

Aspects of the SSC experiments which students liked most

In general, the students who did SSC hands-on practical activities were positive to this approach. They had actually not conducted any experiments before; and most likely any practicals would have been received with acclamation. Students indicated that their involvement in the SSC practical activities gave them the opportunity to manipulate materials and learn from their mistakes. This in turn, students said, build their confidence, enhanced their practical skills and increased their interest towards science in general and chemistry in particular.

Most students also reported that they liked working in small groups. They mentioned that they were afraid to perform experiments by themselves. At first, some were reluctant even to touch the materials. However as some group members push ahead every group member followed and fear subdued. In addition, students commented that the group work enabled them to share ideas. A student, for example, expressed his satisfaction over the group work saying that 'the most joyful was to work in groups helping each other without fear'.

In addition to this, a majority of the students mentioned that they found the SSC kits and experiments easy to use and swift to conduct, safe and economical. They liked the way the materials and chemicals were arranged in the kits enabling them to easily find each apparatus or chemical without wasting time. The fact that students were getting positive results from the experiments also contributed for their positive view towards the SSC approach. Some of the positive comments forwarded by students include the following;

- *Everything was around us. No going here and there, it was easy to use and time saving.*
- *There was no wastage.*
- *I do not have words, but I want to say it was enjoyable.*
- *I love MyLab.*

Asked which experiments they liked most, majority of students mentioned that they liked the experiments on electrical conductivity of aqueous solutions of compounds and the effect of catalyst on the rate of a reaction. The most frequent reasons mentioned included the setting up of the experiments was easy, the results (changes) of the experiments were easy to observe, and the experiments helped them to verify and prove some of the difficult concepts that they had difficulties with. One student put it like this:

> *When we react [mix] copper with dilute HCl solution, there was no change. But there was a change [reaction] when zinc was mixed with HCl; the reaction between zinc and HCl become even faster when we conduct it in the presence of copper. That means the copper increased the rate of the reaction. Copper as a catalyst. I like this part very much. ….I was so confused when I learn [sic.] the theory on factors affecting the rate of reaction but when I do it practically, everything become clear. I investigated myself.*

Difference between the SSC practical lessons and the regular chemistry classes

In general, students mentioned, not surprisingly, that they witnessed a big difference between the SSC based lessons and their regular chemistry classes, and commented in favor of the new approach. They explained that in their regular chemistry classes they were passive listeners while the SSC experiments enabled them to actively participate in different activities including finding the materials from the kits, setting up of apparatus, operating the experiments, observing and reporting results, using the worksheets, answering questions, cleaning working tables and other materials used in the experiments; and arranging all the materials to their original places in the kit. Clearly not all of this would give improved results in a typical "classical chemistry test".

However there is little of the above, which does not fall under an experimentalist's normal tasks. Therefore in order to transpire part of the tacit knowledge of experimental chemistry, these activities are worthwhile. The SSC provided an opportunity to read formulas and names of chemicals on the vials, to deduce explanations of results etc. In short, the students were active, both manually and mentally, and the approach made them think chemistry non-stop.

Asked to forward final comments regarding the small-scale approach of chemistry practical work, a great majority of the students stressed that the SSC approach should be implemented across all schools in the country. Others suggested that a similar approach should also apply for biology and physics classes. Some even suggested for production of the kits in Ethiopia. Though most students were reluctant to indicate drawbacks of the SSC experimentation, a few highlighted problems such as breakage of glass materials (e.g. beaker, test tubes, glass rod), insufficient information before the start of the experiments, lack of clarity in some of the instructions (procedure) of the experiments, lack of previous practical skill of the students themselves, that the teachers were not able to give sufficient support to all groups, some disorder, fear of chemicals, shortage of chemicals in some experiments, and lack of positive results in some experiments.

Some of the problems mentioned were a result of lack of experience of teachers and students on chemistry hands-on activities and could be improved overtime as they make more practice. However, it should be recalled that even laboratories prepared to the teeth may not run smoothly. That experiments seldom are successful at first attempt must be considered a useful experience that contributes to a more realistic understanding of how science develops. Breakage of tiny glass materials, fear of some chemicals, lack of class discipline etc., for example, will never be fully avoided. The way out could be to make advance preparations to tackle the problems. It is of paramount importance for the schools to have a stock of replacement for broken/lost/non-functioning equipment or chemicals, but with more experience, less will be broken.

Teachers' evaluation of the SSC approach (interview)

The interviews were focused on the two-day SSC training, the applicability of the SSC approach in actual lessons and how the approach helped the teachers instruct in a student-centered manner, and what problems were encountered. As a whole, teachers' opinions towards the SSC approach were highly positive. As a result of their participation in the two-day' workshop and in the study in general, teachers felt that their scope of practical work had been increased. The new approach enabled them to do practical work using minimum resources even with large number of students, up to fifty students in ten groups. Most of the SSC hands-on activities can be completed in a shorter time (within the forty minutes class period), which is also an advantage mentioned by the teachers.

The approach helped the teachers promote active learning in their lessons. Timid and shy students who seldom participated in the regular classes were observed participating in their groups during the SSC experiments; in particular girls' involvement was enhanced. The safe and easy to use nature of the SSC kits encouraged participation even further. Students were observed to be highly excited and happy, hardly surprising as this study gave the students a first opportunity to conduct experiments themselves. The teachers emphasized that the SSC approach helped the students develop confidence and an 'I can do' attitude.

All the teachers expressed strong positive views with regard to the importance of the SSC hands-on activities in enhancing students' practical skills, understanding of concepts and in developing positive attitudes towards the subject (chemistry). They expected the impact of the sessions to be long lasting, even having an effect on the students' future careers.

With regard to safety and suitability of the SSC approach for use in classrooms, a teacher put it as follows:

In the small-scale, my students had to use only very small amounts of chemicals. They can use proppets and syringes to transfer liquids. In addition, most of the apparatus are plastic materials; the reagent bottles are very small. Everything was safe. This gave confidence to me and my students to perform the experiments without fear. Furthermore, in this approach everything was ready; the kits were compact and portable and contain almost everything in the same box. There is no wasting time in searching reagents from shelves or stores. Solutions were ready. The manuals give step by step guidance. Everything was ok.

Another teacher also commented that the approach helped to facilitate students' understanding of concepts as follows:

Previously when I was teaching the topic of electrolysis (what is electrolysis? what is cathode? what is anode, what is preferential discharge etc.,) it was very difficult for me to transmit my ideas. But using the SSC, it became easy. I was able to physically show them the anode and the cathode; students were able to see the flow of electricity [glowing of the LED] and the reactions [bubbling of gases] that were taking place at the electrodes by their naked eyes. The same was true with factors affecting rate of reaction; it was difficult for me to convince students whether 'a catalyst facilitates a reaction without undergoing any change for itself'. But using the small-scale experimentation, students had proved that for themselves. You can see the students becoming very happy when they confirm the theory with their own experiment.

Asked to give final comments regarding the SSC approach, all teachers strongly recommended the implementation of the small-scale approach in their schools and in the country as a whole. As one of the teachers expressed it,

This SSC approach must be introduced to all schools in the country. I am sure, if they try it, they will like it.

A number of other studies have reported similar positive views of teachers towards the small-scale approach [e.g. 23, 24, 30, 32, 37, 38, 58]. Mohamed et al. [30], for example, reported that teachers strongly supported the approach saying that it is easier, time saving, can increase class interactions and can enhance the students' performance in various aspects of learning chemistry.

No significant problems were reported. The few mentioned will necessarily be improved as both students and teachers make more practice. The teachers experienced problems identifying some of the equipments in the kit, difficulties fitting some of the equipment, problems cleaning of some of the plastic apparatus, breakage problems in some glass equipment, and problems in getting accurate results. The lack of accurate results were partly due to fact that the the MyLab kit did not include analytical balance and hence measurement of mass in most of the experiments was just an estimation. In addition to this, some reactions were too fast to make accurate observations. Consequently, the results were affected.

Nevertheless, as any experimentalist knows, accurate results are rarely achieved the first time, materials break and stains stubbornly persist. This is part and parcel of doing experimental work – even for SSC. Lack of discipiline, that is too much noise and disorder in the room, was also reported as a problem. Teachers who have been educated using an authoritarian style may avoid engaging students in hands-on practical activities simply for the discomfort and insecurity they feel due to the loss of 'control' in their classes. This part of practicals should be addressed parallel with the training in manipulating the SSC sets.

CONCLUSIONS AND RECOMMENDATIONS

This study explored the possibility and effect of using the SSC approach as a means of implementing chemistry hands-on practical activities in Ethiopian secondary classes without the need for expensive 'traditional' laboratories. Classroom experiences throughout the study period indicated that the approach was helpful in addressing some of the bottle necks that schools and teachers face when trying to implement chemistry practical work. With the SSC MyLab kit, everything the teachers and students needed were at hand and only small amounts of chemicals were consumed, reducing thence costs and waste. In addition, it was observed that the SSC approach led to intense interaction both among the students themselves and between the students and the teacher, thereby providing a positive learning ambiance. Indeed, significant difference in chemistry achievement was observed between the experimental group that was taught using the SSC hands-on approach and the control group that was taught with the traditional approach in favor of the experimental group ($p < 0.05$).

Not surprisingly, the teachers and students regarded the SSC as an effective approach in teaching and learning chemistry. The teachers reported that their participation in the study had broadened their scope of practical chemistry work and that such activities can be performed with minimum resources. In the teachers' opinion, the approach allowed students to carry out experiments by themselves, promoted active learning by enhancing class interactions, and made chemistry class interesting and enjoyable. Both teachers and students appreciated that the SSC was easy to use, safe and less costly.

From the above-mentioned results, it is plausible to conclude that the SSC approach is a commendable option for the Ethiopian secondary chemistry classes. It may enable implementation of chemistry practical work by addressing some of bottle necks and thereby enhancing the quality and relevance of secondary chemistry teaching in the country. However, the need for good planning and extensive follow-up must not be underestimated. Training in the use of the kit, monitoring the implementation, continuous support to teachers and a steady system for acquiring spare parts are key factors in the successful implementation of the SSC approach in schools. In addition, attention should be given to time allocation, class size, and workload calculation of science practical classes. Future work shall focus on familiarizing the small-scale approach throughout schools and higher learning institutions in the country.

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Appendix 1
Student pre- and post-tests questions

Time allocated: 90 minutes

Name _____________________ Class and section _____ Sex _____ age ______

Part I: Choose the correct answer and circle the letter of your choice (1 mark each)

1. Solid sodium chloride is a bad conductor of electricity because;
   A. It contains only molecules
   B. It does not possess ions
   C. The ions in it are not free to move
   D. It does not contain free molecules
2. In the electrolysis of sulphuric acid using platinum electrodes
   A. Hydrogen is evolved at the cathode
   B. Ammonia is produced at the anode
   C. Chlorine is obtained at the cathode
   D. Sulphur dioxide is produced at the anode
3. It has been observed that gaseous hydrogen chloride is a very poor conductor of electricity but a solution of hydrogen chloride gas in water is good conductor of electricity. This is due to the fact that
   A. Water is good conductor of electricity
   B. Hydrogen chloride gas in water solution ionizes
   C. A gas is non-conductor but a liquid conducts electricity
   D. None of the above
4. The aqueous solution of which of the following compounds is decomposed on passing an electric current?
   A. Cane sugar
   B. Urea
   C. Methanol
   D. Potassium iodide
5. The electric conduction of a salt solution in water depends on the
   A. size of its molecules
   B. Shape of its molecules
   C. Size of solvent molecules
   D. Extent of its ionization
6. The rate of a chemical reaction can be expressed in
   A. Grams per mole
   B. Energy consumed per mole.
   C. Volume of gas evolved per unit time.
   D. Moles formed per litre of solution
7. Consider the following reaction:

   $$2N_2O_5 \rightarrow 4NO_2 + O_2$$

   At a certain temperature the rate of decomposition of N_2O_5 is 2.5×10^{-6} mol/s. The rate of formation of NO_2 is:
   A. 1.0×10^{-5} mol/s
   B. 1.3×10^{-6} mol/s
   C. 2.5×10^{-6} mol/s
   D. 5.0×10^{-6} mol/s

8. Consider the following reaction:
   $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
   At a certain temperature, 1.0 mol CH_4 is consumed in 4.0 minutes. The rate of production of H_2O is
   A. 0.25 mol/min
   B. 0.50 mol/min
   C. 2.0 mol/min
   D. 8.0 mol/min
9. Which combination of factors will affect the rate of the following reaction?
   $Zn(s) + 2HCl\ (aq) \rightarrow ZnCl_2\ (s) + H_2(g)$
   A. temperature and surface area only
   B. temperature and concentration only
   C. concentration and surface area only
   D. temperature, concentration and surface area
10. Magnesium metal reacts rapidly with hydrochloric acid in an open beaker to produce aqueous magnesium chloride and hydrogen gas. Which of the following could be used to measure the rate of this reaction?
    A. the volume of the solution
    B. the colour of gas produced
    C. the concentration of the chloride ion
    D. the mass of the beaker and its contents
11. Consider the following factors:
    I. Concentration of reactants.
    II. Temperature of reactants.
    III. Surface area of reactants.

The factors that affect the rate of a chemical reaction between two gases are
   A. I and II only.
   B. I and III only.
   C. II and III only.
   D. I, II and III
12. To increase the rate of a reaction, there must be
    A. A decrease in the frequency of collisions.
    B. An increase in the frequency of collisions.
    C. A decrease in the frequency of successful collisions.
    D. An increase in the frequency of successful collisions.
13. Which of the following statements about catalysts is true?
    A. Catalysts work by increasing the temperature of the reaction
    B. Catalysts can be recovered chemically unchanged after the reaction
    C. Catalysts increase the energy required for the reaction to take place
    D. Catalysts are always powdered solids
14. If we increase the concentration of a reactant, what happens to the collisions between particles?
    A. There are fewer collisions
    B. There are the same number of collisions but they have less energy
    C. There are the same number of collisions but they have more energy
    D. There are more collisions

15. Why does the rate of reaction increase when powdered calcium carbonate is used instead of cubes of marble?
    A. There is an increase in concentration
    B. There is an increase in temperature
    C. There is an increase in surface area
    D. Powdered calcium carbonate is a catalyst

Part II: Answer the following questions in the space provided

16. An aqueous solution that contains positive and negative ions can conduct an electric current. Write down the chemical formulas for the ions formed in aqueous solution by the following compounds. (2 marks)

e.g. NaCl (aq) →	Na^{+}(aq) + Cl^{-}(aq)
Compounds in aqueous solution	The ions formed in aqueous solution
a)KCl (aq) →	
b)Na_2SO_4(aq) →	

17. Define electrolysis (1 mark)

    ____

18. An experiment was carried out to look at the reaction between magnesium and hydrochloric acid. The word equation for this reaction is:

    Magnesium + Hydrochloric Acid → Magnesium Chloride +Hydrogen

    a) What would you observe when this reaction is taking place? (1 mark)

    ____

    b) Give three ways in which the rate of reaction could be increased **(**3 marks**)**
       i) ____
       ii) ____
       iii) ____

19. You are provided with a piece of zinc metal (zinc granule), zinc dust; dilute HCl, ice-bath, test tubes, water bath, burner. Using the materials provided, devise an activity to study the factors affecting the rate of the reaction between zinc and dilute HCl (3 marks)

    ____

Appendix 2

SSC student worksheet manual (for experiment 1)

Experiment 1: electrical conductivity of ionic compounds

Objective: To test the electrical conductivity of the aqueous solutions of some compounds

Apparatus: MYLAB apparatus stand, water bowl, spatula, 9-volt battery, set of conducting, wires (connecting wires), battery connection, two copper electrodes, and glass stirring-rod

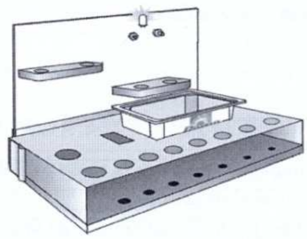
Chemicals: Distilled water, sodium chloride, copper sulphate, calcium chloride, sodium bicarbonate, iron (III) chloride, table sugar, Na_2CO_3.

Safety

- Sodium carbonate (Na_2CO_3) is an irritant. It is irritating to the eyes. In case of contact with the eyes, rinse immediately with plenty of water and seek medical advise.do not breathe the dust.
- Copper (II) sulphate ($CuSO_4$) is harmful if swallowed. It is irritating to eyes and skin. Do not breathe the dust.

Procedure

1. Set up the apparatus as shown in the sketch



Source: MyLab (2012)

2. Fill the water bowl with water to the brim
3. Add four spatulas of NaCl into the water in the water bowl and stir it with a glass rod until the salt dissolves
4. Follow the steps below (step 5-8) to complete the apparatus setup.
5. Place two electrodes (copper electrodes) in the water and connect them as shown in the sketch
6. Connect the red (positive) conducting wire of the battery connection to the red or positive terminal of the LED (light emitting diode).
7. Connect the black (negative) conducting wire of the battery connection to the end of the electrode protruding from the water.
8. Use another separate conducting wire to connect the end of the other electrode (also protruding from the water) to the black or negative terminal of LED. Note your observations
   Note: Use the signs of the battery terminals to determine which is the positive and which is the negative electrode in the water bowl
9. Repeat the experiment using the following compounds: distilled water only, sodium carbonate, copper sulphate, calcium chloride, sodium bicarbonate, iron (III) chloride, table sugar. Note your observations

Observations and analysis

1. In step 8 above, what do you observe when you look at the LED? Explain your observation
2. In step 9 above, the aqueous solutions of some of the compounds conduct electricity while others do not? Explain why.
3. Classify solutions of these compounds as electrolytes and non-electrolytes
4. An aqueous solution that contains positive and negative ions can conduct an electric current. Write down the chemical formulas for the ions formed in aqueous solution by the following compounds.

e.g. NaCl (aq) →	$Na^+(aq) + Cl^-(aq)$
Compounds in aqueous solution	The ions formed in aqueous solution
KCl (aq) →	
$MgCl_2(aq)$ →	
$Na_2SO_4(aq)$ →	

5. What is an electrolyte?
6. When is a compound a strong electrolyte and when is a compound a weak electrolyte?

7. Will KCl(aq), $MgCl_2$(aq), and Na_2SO_4 (aq) be strong or weak electrolytes? Explain your answer.

8. What do you learn from this experiment?

Clean up time

MYLAB apparatus	Waste disposal
Wash and clean apparatus according to instructions	
Wash test tubes with test tube brush and rinse well. Dry or place upside down in apparatus stand	Dilute the waste with lots of water before disposing of the waste in the outside drain or on the ground
Close lids of chemicals properly and put back in the correct place	
Pack set according to packing instructions	
WASH HANDS on completion of experiments!!!	

Source: MyLab [2012]

Appendix 3: SSC teachers guide manual (for experiment 1)

Experiment 1: electrical conductivity of ionic compounds

Objective: To test the electrical conductivity of the aqueous solutions of some compounds

Apparatus: MYLAB apparatus stand, water bowl, spatula, 9-volt battery, set of conducting wires (connecting wires), battery connection, two copper electrodes and glass stirring-rod

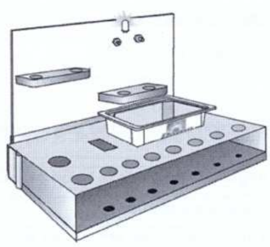
Chemicals: Distilled water, sodium chloride, copper sulphate, calcium chloride, sodium bicarbonate, iron (III) chloride, table sugar, Na_2CO_3.

Safety

- Sodium carbonate (Na_2CO_3) is an irritant. It is irritating to the eyes. In case of contact with the eyes, rinse immediately with plenty of water and seek medical advise.do not breathe the dust.
- Copper (II) sulphate ($CuSO_4$) is harmful if swallowed. It is irritating to eyes and skin. Do not breathe the dust.

Procedure

1. Set up the apparatus as shown in the sketch



Source: MyLab (2012)

2. Fill the water bowl with water to the brim
3. Add four spatulas of NaCl into the water in the water bowl and stir it with a glass rod until the salt dissolves
4. Follow the steps below (step 5-8) to complete the apparatus setup.

5. Place two electrodes (copper electrodes) in the water and connect them as shown in the sketch
6. Connect the red (positive) conducting wire of the battery connection to the red or positive terminal of the LED (light emitting diode).
7. Connect the black (negative) conducting wire of the battery connection to the end of the electrode protruding from the water.
8. Use another separate conducting wire to connect the end of the other electrode (also protruding from the water) to the black or negative terminal of LED. Note your observations Note: Use the signs of the battery terminals to determine which is the positive and which is the negative electrode in the water bowl
9. Repeat the experiment using the following compounds: distilled water only, sodium carbonate, copper sulphate, calcium chloride, sodium bicarbonate, iron (III) chloride, table sugar. Note your observations

Observations and analysis

1. In step 8 above, what do you observe when you look at the LED? Explain your observation.

   The LED burns brightly which shows that an aqueous solution of NaCl conducts electricity strongly.

2. In step 9 above, the aqueous solutions of some of the compounds conduct electricity while others do not? Explain why.

   Yes, aqueous solutions of sodium carbonate, copper sulphate, calcium chloride, sodium bicarbonate, iron (III) chloride conduct electricity strongly. On the other hand table sugar do not conduct electricity because it is a non-ionic compound

3. Classify solutions of these compounds as electrolytes and non-electrolytes

Electrolytes: aqueous solutions of sodium carbonate, copper sulphate, calcium chloride, sodium bicarbonate, iron chloride
Non-electrolyte: aqueous solution of table sugar

4. An aqueous solution that contains positive and negative ions can conduct an electric current. Write down the chemical formulas for the ions formed in aqueous solution by the following compounds.

e.g. NaCl (aq) →	Na^+(aq) + Cl^-(aq)
Compounds in aqueous solution	The ions formed in aqueous solution
KCl (aq) →	**K^+(aq) + Cl^-(aq)**
$MgCl_2$(aq) →	**Mg^{2+}(aq) + 2Cl^-(aq)**
Na_2SO_4(aq) →	**2Na^+ + SO_4^{2-}(aq)**

5. What is an electrolyte?

   An electrolyte is a substance that forms ions in water or in the molten state and therefore an electrolyte can conduct an electric current.

6. When is a compound a strong electrolyte and when is a compound a weak electrolyte?

   A strong electrolyte forms lots of ions in aqueous solution and a weak electrolyte forms very little ions in aqueous solution

7. Will KCl(aq), $MgCl_2$(aq), and Na_2SO_4 (aq) be strong or weak electrolytes? Explain your answer.

   All of the compound are very soluble in water and are therefore strong electrolytes. They form lots of ions in solution.

8. What do you learn from this experiment?

   You have learned that aqueous solutions of ionic compounds like NaCl conduct

electricity while aqueous solutions of covalent compounds like table sugar are non-electrolytes. The reason is that ionic compounds dissolve in water and produce a lot of ions. This enables them to be strong conductors of electricity in their solution form. On the other hand covalent compounds do no dissolve in water to produce ions. Hence they do not conduct electricity.

Clean up time

MYLAB apparatus	Waste disposal
Wash and clean apparatus according to instructions	
Wash test tubes with test tube brush and rinse well. Dry or place upside down in apparatus stand	Dilute the waste with lots of water before disposing of the waste in the outside drain or on the ground
Close lids of chemicals properly and put back in the correct place	
Pack set according to packing instructions	
WASH HANDS on completion of experiments!!!	

Source: MyLab [2012]

Appendix 4: List of main apparatus/equipment and chemicals which are required to perform the mandatory chemistry experiments specified in the Ethiopian secondary chemistry syllabus

Apparatus/equipment				**Chemicals**					
1	Beakers of various sizes	34	light bulb	1	Acetic acid	34	Gentian violet	67	Sodium chloride
2	bunsen burner	35	litmus papers	2	Alcohol	35	glycerine	68	sodium dichromate
3	Burette	36	Measuring cylinder	3	aluminium metal	36	graphite	69	Sodium hydroxide
4	carbon rod	37	melting point tube	4	aluminium oxide	37	hexamethylenediamine	70	sodium metal
5	Clamp	38	nichrome wire	5	ammonia solution	38	hexane	71	sodium peroxide
6	combustion tube	39	pH meter	6	Ammonium nitrate	39	hydrochloric acid	72	sodium sulphate
7	condenser	40	Pipette	7	ammonium phosphate	40	hydrogen gas	73	sodum carbonate
8	conical flask	41	platinium wire	8	ammonium sulphate	41	hydrogen peroxide solution	74	starch
9	Cork	42	pneumatic trough	9	Ba(ClO2)2	42	iodine crystals	75	Sulfuric acid (18M)
10	cotton wool	43	porcelain	10	barium chloride	43	iron (II) nitrate	76	Sulphur powder
11	deflagrating spoon	44	power supply (DC)	11	barium nitrate	44	Iron fillings	77	tin metal
12	delivery tube	45	quickfit apparatus	12	barium peroxide	45	iron metal	78	toluene
13	distillation flask	46	reagent botles	13	benzene	46	lead bromide	79	universal indicator
14	Doppers	47	round bottom flask	14	Bile	47	lead iodide	80	wooden spirit
15	dropping funnel	48	rubber tube	15	boiling chips	48	lead metal	81	yeast
16	dry cells	49	sand paper	16	bromine water	49	lead oxide	82	zinc metal

17	electrodes of different types	50	separatory funnel	17	calcium carbide	50	magnesium metal	83	zinc oxide
18	electronic balance	51	spatula	18	calcium carbonate	51	magnesium oxide	84	zinc strip
19	Erlenmeyer flask of different sizes	52	Stand	19	calcium hydroxide	52	magnesium ribbon	85	zinc sulphate
20	Evaporating dish	53	Stirrer	20	calcium metal	53	manganese dioxide		
21	filter funnel	54	stoppers	21	calcium oxide	54	marble chips		
22	filter paper	55	stopwatch	22	carbon tetrachloride	55	mercury		
23	forceps	56	switch	23	cobalt chloride	56	methyl red		
24	funnel	57	test tube holders	24	copper carbonate	57	naphtalene		
25	gas jar	58	test tube stand	25	copper metal	58	nitric acid		
26	gas jar lid	59	Test tubes	26	copper oxide	59	phenolphthalein		
27	gas syringe	60	Thermometer	27	copper powder	60	potasium thiocynanate		
28	Glass rod	61	tongs	28	copper strip	61	potassium chloride		
29	gloves	62	tripod	29	copper sulphate	62	potassium iiodide		
30	goggles	63	U-tube	30	copper wire	63	Potassium permanganate		
31	graphite electrodes	64	voltameter	31	cupper chloride	64	silver nitrate		
32	insulated electric wires	65	Watch glass	32	Distilled water	65	Sodium acetate		
33	iron rod	66	wire gauze	33	ethanol/alchol	66	sodium carbonate		