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Enquiries and manuscripts should be addressed to the Editor-in-Chief: email eic@faschem.org, PO Box 2305, Addis Ababa, Ethiopia.

CONTENTS

DESIGN AND TESTING OF THE MICRO FILTER PAPER FUEL CELL

Qi.Zhao[1], John Bradley[2], K.M. Chan[3], and N.H.Zhou[4*]
(1) Senior teacher, Hangzhou No. 9 high School, Hangzhou, 310020, China
(2) Professor, University of Witwatersrand, Wits School of Education, Johannesburg, South Africa
(3) Director, Micro Chem Lab, Hong Kong, China
(4) Prof. & Director, Chinese Microscale Laboratory Center, Hangzhou Normal University, Hangzhou, 311121, China
Email: John.Bradley@wits.ac.za

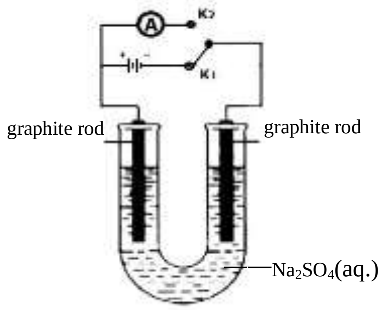
ABSTRACT

A micro filter paper fuel cell (MFPFC) has been developed. The hydrogen and oxygen used in the fuel cell are formed on the electrodes by electrolysis with solar energy. Illustrating a method of obtaining clean energy. Sensor-based and micro-scale designs serve as exemplars for Education for Sustainable Development (ESD) [1] in school-level chemistry experiments. They are expected to be capable of arousing students' participation in creative and innovative designs, appreciation of "Green Awareness", "Sustainable Development" and their necessity in a worldwide scenario. *[African Journal of Chemical Education—AJCE 12(2), July 2022]*

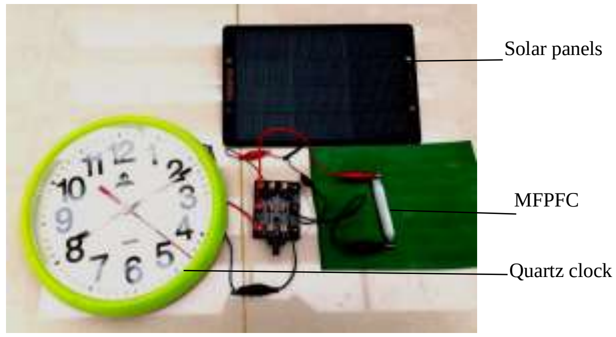
INTRODUCTION

In the traditional experimental device of H_2-O_2 fuel cell (Fig.1, switches K_1 ON), the electrolysis of a dilute solution of Na_2SO_4 with graphite electrodes liberates oxygen at the anode and hydrogen at the cathode [2][3]. This step is to provide fuel for the fuel cell (step①). After the electrolysis (switches K_1 out and K_2 on), the two electrodes with their absorbed gases form a voltaic cell, which is the simplest H_2-O_2 fuel cell (step②). In this cell, the electrode with oxygen is the positive pole and the electrode with hydrogen is the negative pole.

The two-step operation illustrates the basic principle of H_2-O_2 fuel cell, but the traditional experimental device has lots of drawbacks, including unacceptable amount of reagent used, unstable and rapid drop of discharge voltage and use of a battery (not a clean source of energy) for electrolysis. There are many papers on the microscale approach to fuel cell experiments [4-9]. In these, microwell plates are the basic reactors which use maybe 5 ml electrolyte. Our proposed design uses wet filter paper attached to a pencil lead as electrode and two such electrodes form a micro filter paper fuel cell (Fig.2). It uses less than 0.3 ml of electrolyte. The unfueled design needs a solar cell to form fuel and oxygen by electrolysis to establish the initial store of these on the electrodes. This micro filter paper fuel cell (MFPFC) can illuminate an LED for 5 mins, operate a quartz clock for 10 mins and drive a toy car for the distance of 5 meters.



(Fig. 1) Traditional experiment of oxygen-hydrogen fuel cell in textbook



(Fig. 2) MFPFC device

MATERIALS AND EQUIPMENT USED IN TESTING PERFORMANCE VARIABLES

Material/reagent/ description	Qty	Material/reagent/ description	Qty
Zhonghua Brand pencil lead (HB, 2B) 8cm (length) 2mm (dia)	2 pcs	1M H_2SO_4(aq)	1 ml
Graphite rod dismantled from used dry cell (12 mm dia×5 cm)	2 pcs	1M NaOH(aq)	1 ml
Sat. Na_2SO_4(aq)	2 ml	Qualitative filter paper (Shuangquan Brand, 101, 102)	Suitable number
1M Na_2SO_4(aq)	1 ml	Quantitative filter paper (Shuangquan Brand, 201, 203)	Suitable number
Sat. Na_2SO_3(aq)	1 ml	Napkin sheet	Suitable number
Sat. Na_2CO_3(aq)	1 ml	Deionized water	30 ml
Sat. K_2SO_4(aq)	1 ml		

Equipment description	Qty
Data logger (Vernier, LabQuest Mini)	1
Voltage sensor (Vernier, DVP-BTA)	1
Current sensor (Vernier, DCP-BTA)	1
Solar cell (MYGX 5W08)	1
Connecting wire and clip	6
Stopwatch	1
Thermometer, (-10 to 100) ºC	1
Beaker, 25 ml	2
Pipette (Dropper), 4 ml	12

DESIGN RATIONALE

Half-cell reactions of a concentration-dependent oxygen/hydrogen fuel cell are as follows (Ref: Wikipedia, Standard Electrode Potential, data page):

Reduction at cathode (positive pole): $O_2(g) + 4H^+(aq) + 4e \rightleftharpoons 2H_2O(l)$ $E^{\circ} = +1.23$ V

Oxidation at anode (negative pole): $2H_2(g) + 4OH^-(aq) - 4e \rightleftharpoons 4H_2O(l)$ $E^{\circ} = -0.828$V

Overall cell reaction: $O_2(g) + 2H_2(g) + 4H^+(aq) + 4OH^-(aq) \rightleftharpoons 6H_2O(l)$

Cell diagram of a concentration-dependent oxygen/hydrogen fuel cell consists of the following two half-cells:

$$\ominus \qquad\qquad\qquad\qquad \oplus$$

$$C_{(s)} \mid H_2(g), OH^-(aq) \parallel O_2(g), H^+(aq) \mid C_{(s)}$$

The carbon electrode with absorbed oxygen gas acts as the positive pole and that with absorbed hydrogen gas acts as the negative pole.

Nernst equation:

$$E = E^{\phi} - \frac{RT}{nF}\ln\frac{[Red]}{[Oxid]} = E^{\phi} - \frac{0.059}{n}\lg\frac{[Red]}{[Oxid]} \quad (T=298K)$$

Nernst equations for the two half-cells:

$$E_{(right)} = +1.23\ V - \frac{0.059}{4}\lg\frac{1}{[H^+]^4\, p_{O_2}} \quad \text{w.r.t. standard hydrogen electrode .....(1)}$$

$$E_{(left)} = -0.828\ V - \frac{0.059}{4}\lg\frac{(p_{H_2})^2[OH^-]^4}{1} \quad \text{w.r.t. standard hydrogen electrode .....(2)}$$

If $[H^+]$ and $[OH^-] = 1\ mol\ l^{-1}$ and gas pressures of H_2 and O_2 are both 1 atm,

$$E_{(cell)} = E_{(right)} - E_{(left)}$$

$$E_{(cell)} = (1.23\ V) - (-\ 0.828\ V) = 2.058\ V,$$

The Nernst equation shows the e.m.f. of the cell is dependent on gas pressures of H_2 and O_2. The higher the pressure of oxygen, the larger the cell e.m.f. and the same for hydrogen. We could not measure these two variables but it was expected that the pressures of the absorbed oxygen and hydrogen should be higher than atmospheric pressure, as they were contained temporarily by the wet filter paper.

Suppose the solution concentrations around the electrodes after electrolysis are: $[H^+] = [OH^-] = 5$ mol l^{-1} and the gas pressures of H_2 and O_2 are both 1.5 atm. Substituting these values into eqt (1) and (2), we have:

$$E_{(right)} = [1.23 - \frac{0.059}{4} \times \lg\frac{1}{5^4 \times 1.5}]\ V = 1.274V$$

$$E_{(left)} = [-\ 0.828 - \frac{0.059}{4} \times \lg(1.5^2 \times 5^4)]\ V = -\ 0.874V$$

$$E_{(cell)} = (1.274\ V) - (-\ 0.874\ V) = 2.148V$$

The voltage of the fuel cell during discharge remained fairly stable at 2V (Fig. 3), which is consistent with the calculated value.

Innovative use of filter paper

The porous nature of graphite coupled with the absorbing property of filter paper is made use of in fabricating the MFPFC. Tight wrapping of electrodes by using wet filter paper enhances a high concentration of gaseous reactants, liberated after electrolysis, for cell reactions. This provides a way to increase the capacity of the fuel cell.

FABRICATION OF MFPFC

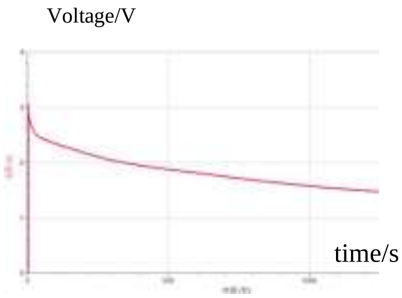
Take two pieces of HB pencil lead, each having a length of 8 cm and with a diameter of 2 mm. Separately wrap each twice with a section of 7 cm (width) filter paper, allowing 1 cm protrusion of pencil lead for electrical conduction. Place the two prepared electrodes in opposite direction so that the lead tips do not face each other. Wrap the two electrodes together with filter paper by a few rounds. Tie them up tightly by threads of string. Add drops of Na_2SO_4 solution (> 0.5 mol l^{-1}) to the bundled filter paper until it is completely soaked with the reagent. Connect the pencil leads to a solar cell (6V) and start electrolysis for 2 minutes, ensuring enough time for the generated oxygen and hydrogen gases to be absorbed by the pencil lead electrodes. A micro oxygen-hydrogen fuel cell is created when the solar cell is disconnected.

MFPFC VS TRADITIONAL FUEL CELL (Fig 1)

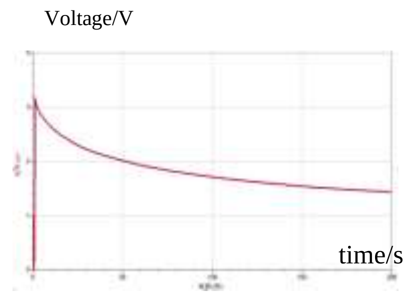
A voltage sensor is used to load the signal source (fuel cell) and the rate of drop of voltage of the fuel cell upon discharge over time was measured, as shown in Fig. 3.

Fig. 4 shows the voltage decay curve using MFPFC while Fig. 5 displays the corresponding curve for a traditional fuel cell.

(Fig. 3) Voltage decay curve test setup

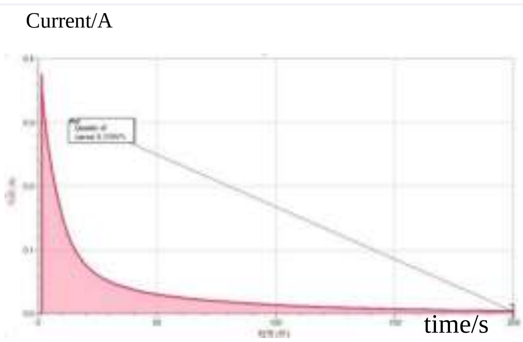


(Fig. 4) Voltage decay curve displayed by MFPFC

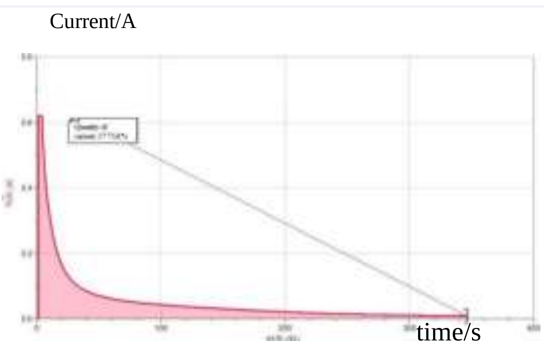


(Fig. 5) Voltage decay curve displayed by a traditional fuel cell

Replacing the voltage sensor by a current sensor for decay curve display overtime and by integrating current passed vs time, discharge current capacity for the two cases are illustrated in Fig. 6 and 7. Parameter values are listed in Table (1).



(Fig. 6) Current decay curve of MFPFC



(Fig. 7) Current decay curve of a traditional fuel cell

Table (1):

	Time required for voltage to drop to 1.5V / s	Peak current / A	Current half-life / s	Quantity of electricity / C
Traditional fuel cell	220	0.62	10.6	17.71
MFPFC	1184	0.37	8.0	6.34

(Table 1) Comparison of performance between MFPFC and traditional fuel cell

As shown in Table (1), output current of MFPFC is less than that of a traditional fuel cell, but the voltage discharge time is significantly longer. This feature is at an advantage for MFPFC to drive a quartz clock or a toy car which consumes weak current.

FACTORS AFFECTING PERFORMANCE OF MFPFC

a. Experimental method adopted

The suitable conditions for MFPFC to operate were tested sequentially according to the following list of variables. All measurements were made at an ambient temperature of 20^{o}C.

b. Choice of variables

1. Voltage of electrolysis

Various voltage supplies were used for the electrolysis startup for a duration of 2 minutes. A clean energy source using solar cell (MYGXS5W08) outputs 6V and 0.3A under decent sunlight irradiation. Table (2) shows the optimum supply voltage is 6V and a solar cell suits the design purpose, especially it meets the green requirement.

Table (2)

Electrolysis voltage / V	Time taken for MFPFC to attain 1.5 V / s
7.5	895
6.0	1184
4.4	351
2.7	103

(Table 2) Different electrolysis voltage for a duration of 2 mins

2. Time of electrolysis

As shown in Table (3), inspection of voltage decay time shows an electrolysis time of 2 or 3 minutes gave better results. Considering the amount of gas released factor and the small difference between voltage decay time for a 2 or 3 minute electrolysis time duration, the 2 minute time for electrolysis is considered to be the best duration time.

Table (3):

Electrolysis (6V) time / min	Time taken for MFPFC to attain 1.5 V / s	Amount of gas released from electrode
0.5	261	Small
1	745	Medium
2	1184	Large
3	1414	Very large

(Table 3) Voltage decay and electrolysis time

3. *Nature of electrode*

The device was tested with different kinds of graphite rod and ways of bundling them together. To remove the effect of organic residues and enhance the porosity of electrode, selected samples were heated strongly for a period of time. Table 4 shows single HB pencil lead performed better, and heating is not a suitable factor to be considered.

Table (4)

	Nature of electrode					
	Graphite rod dismantled from used dry cell	Three HB pencil leads bundled together	Single HB pencil lead (strongly heated)	Single HB pencil lead (unheated)	Single 2B pencil lead (strongly heated)	Single 2B pencil lead (unheated)
Time to attain 1.5 V / s	228	223	901	1184	1325	832

(Table 4) Discharge time and various kind of electrodes

4. Nature of electrolyte

Table 5 shows sat. Na_2SO_4 solution as electrolyte outperformed others tested.

Table (5)

	Nature of electrolyte					
	Sat. Na_2CO_3 (aq)	Sat. Na_2SO_3 (aq)	Sat. K_2SO_4 (aq)	Sat. Na_2SO_4 (aq)	1 mol l^{-1} NaOH(aq)	1 mol l^{-1} H_2SO_4(aq)
Time to attain 1.5 V / s	256	72	782	1184	50	131

(Table 5) Discharge time and various kind of electrolytes

5. Concentration of electrolyte

As shown in Table 6, a concentration of 0.5 mol l^{-1} performed better.

Table (6)

	Concentration of Na_2SO_4 solution					
	Saturated	1 mol l^{-1}	0.5 mol l^{-1}	0.25 mol l^{-1}	0.125 mol l^{-1}	0.0625 mol l^{-1}
Time to attain 1.5 V / s	1184	1124	1534	633	368	333

(Table 6) Discharge time and different concentrations of electrolytes

6. Nature of wrapping material

Various types of wrapping material were tested against voltage decay time of the constructed MFPFC. Table 7 shows the Shuangquan Brand 102 filter paper was the best choice.

Table (7)

	Type of wrapping material				
	Fast qualitative filter paper (101)	medium qualitative filter paper (102)	Fast quantitative filter paper (201)	Slow quantitative filter paper (203)	Napkin
Time to attain 1.5 V / s	1127	1184	992	969	1086

(Table 7) Effect of using different types of wrapping material

7. Dependence on temperature

The device was subjected to environmental temperatures of 6^{o}C and 20^{o}C. Table 8 shows a low temperature surrounding shortened the discharge duration time, a common phenomenon of dry cells. Investigation into methods of lengthening cell lifetime in low temperature weather conditions may be a topic for class discussion.

Table (8)

	Environmental temperature / ^{o}C	
	6	20
Time to attain 1.5 V / s	533	1184

(Table 8) Effect of temperature on discharge to 1.5 V

As shown by the above findings, the suitable conditions for operating a MFPFC are summarized by Table (9):

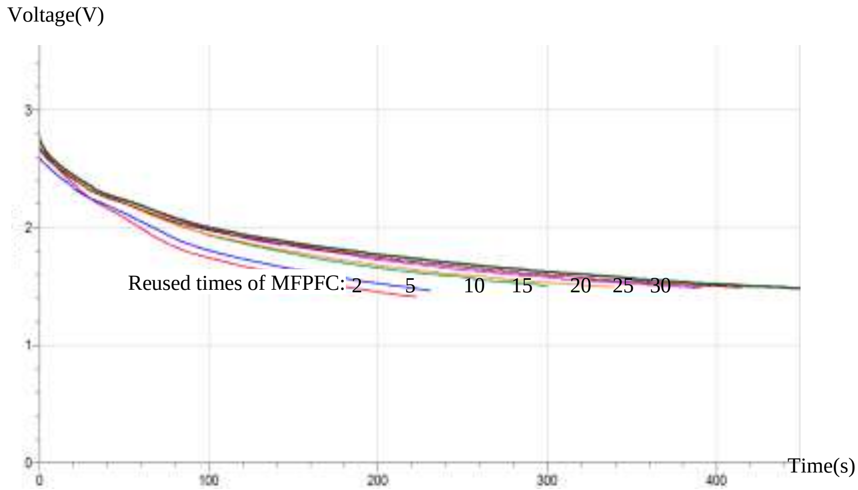
Table (9)

MFPFC specifications	
Electrode	Two pieces of HB pencil lead, 8 cm (length) by 2mm (dia), wrapped by filter paper to be wet with electrolyte
Electrolyte	0.5M Na_2SO_4 (aq.)
Environmental temperature / ºC	20
Initial electrolysis	
Duration of electrolysis / min	2
Voltage of electrolysis / V	6

(Table 9) Specifications of MFPFC and initial electrolysis

TESTING THE REUSE OF MFPFC

After the discharge of the MFPFC, a few drops of the electrolyte can be added to the micro fuel cell for keeping the filter paper wetted, then the electrolysis and discharging progress can be conducted again. We found that the MFPFC can be used repeatedly several times.



(Fig. 8) Voltage decay displayed by the used repeatedly MFPFC

Figure 8 shows the voltage decay curves displayed by the reused MFPFC discharged with a 220 Ω resistor, the digits indicating the number of times that the MFPFC has been reused.

CONCLUSION

The MFPFC was developed for use in school chemistry curricula which refer to Green Awareness and Sustainable Development. We have shown how convenient it can be for teachers and learners in school classrooms with limited resources. Our remaining concern is that teachers and learners understand the relation of what they observe in the classroom at microscale level to the global aim of sustainable development. The following points may help teachers establish this relationship and thereby achieve the broader educational aims of the curricula mentioned.

1. The fuel for the MFPFC (hydrogen) is produced by electrolysis of water. This process requires electrical energy and this must be generated by sustainable methods. This means avoiding electricity from coal-fired power stations and instead using solar energy resources. This is shown here by the use of a solar panel to cause the electrolysis at the start: simply plugging in to a traditional power supply or battery (as in Fig 1) is likely to confuse the sustainable development message.
2. On industrial scale the hydrogen produced is stored and/or transmitted to industrial users (eg for ammonia synthesis) and for users of hydrogen fuel cells. The fuel cell users do not electrolyse water! We do so here and both the hydrogen and oxygen are formed and 'stored' on the electrodes of the fuel cell itself. Bulk storage of the hydrogen does not take place in our experiments. We do not see the hydrogen (or oxygen). Separate microscale electrolysis of water can provide proof of the formation of these products.
3. The MFPFC is described as a fuel cell on the understanding that its fuel is 'stored' on one electrode. Strictly, cells are called fuel cells when the cell is a voltaic cell able to operate continuously as long as fuel is supplied. The MFPFC may claim to be a fuel cell as it can be used repeatedly provided its store of hydrogen and oxygen is replenished (see reuse of MFPFC).

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ASSESSMENT OF CURRENT STATUS OF HANDS ON, MINDS ON AND HEARTS ON ACTIVITY DURING SCIENCE SESSION: THE CASE OF PRIMARY SCHOOLS IN WOLDIA TOWN

Eshetu Desalegn Alemneh
Woldia College of Teaches Education,
Department of Natural Science
DEd candidate at Bahir Dar University, Ethiopia
E-mail: eshetu1976@gmail.com

ABSTRACT

The study was conducted to assess the status of hands on, minds on and hearts on activity during science session and students' attitude towards science subject at full cycle primary schools in Woldia Town. For this study descriptive survey approach was applied and four scaled items questionnaire was employed for 425 students, observation of lab rooms and unstructured interview was employed for laboratory assigned teachers to triangulate the responses of the students. Accordingly, the results indicated that, large number of participants in this study did not have positive attitude towards science. Only 62.34% of the respondents had positive attitude towards science subjects while 37.66% of the respondents do not have positive towards science subjects. Likewise, only 50.51% of students indicated that they were satisfied with the method of learning science subjects (hands on, minds on and hearts on activities) while 49.49% indicated that the students were not satisfied with the method of learning science subjects (luck of hands on, minds on and hearts on activity during science class). In relation to the availability of adequate laboratory 53.92% of the students indicated that the school laboratory was not appropriate for science teaching while 46.08% responses indicated the laboratory supports science teaching. The data obtained from the questionnaire was confirmed by unstructured interview and observations). In view of conclusion, the method of teaching science associated with the luck of hands on, minds on and hearts on activity and the attitudes of the students did not have sound in Woldia Town full cycle primary schools. The schools should be evaluated to improve the students' academic result in related to cognitive, psychomotor, and affective educational domains. [African Journal of Chemical Education—AJCE 12(2), July 2022]

INTRODUCTION

Background of the study

Nowadays quality education in schools has been a topic of discussion everywhere in the globe. Quality education is a system of learning that produces well educated individuals who can handle matters of concern within their area of study proficiently [1]. For a country to develop, it must have adequate human capital to do so. The human capital is obviously obtained through sound education. It is believed that education is a pivotal part of human development, and can positively influence standards of living, health, and governance.

Education, particularly science and technical education, is the ‘driving force’ to turn the nation’s economy around and usher in the desired technological advancement. Acquisitions of appropriate scientific and technological skills are necessary to tackle the challenge presented by the evolving needs of modern workplace in our industries and the ever-growing non-formal sector. Science and technology are the basic tools for the developments of industries and nation as a whole [2].

Education and training systems that responds adequately to these demands will, therefore, contribute to the efforts to overcome the growing unemployment and marginalization of majority of the populace. In science teaching-learning ideas could be organized to extract the scientific consensus model and highlight the differences between these and the students' often alternative ideas [3]. By providing access to appropriate learning experience designed to broaden skills and knowledge (hands on, minds on and hearts on activity) can increase achievement in science education and significantly improve the fortunes of the unemployed, thereby reducing poverty [4].

Science teaching is supposed to be result oriented and students centered, and this can only be achieved when students are willing and the teachers are favorably disposed, using the appropriate methods and resources in teaching science [5]. Most students are curios; they need to be actively involved in the learning process in which they are continuously equipping, testing, speculating, and building their own personal construct and knowledge. In science, students need to actively perform hands on, minds on and hearts on to construct their own personal awareness and meaning about science concepts.

"A child best learns to swim by getting into water; likewise, a child best learns science by doing science" [6]. Doing science, as opposed to simply hearing or reading about it, engages students and allows them to test their own ideas and build their own understanding [7]. Hands-on (skill based) science is defined mainly as any instructional approach involving activity and direct experience with natural phenomena or any educational experience that actively involve students in manipulating objects to gain knowledge (minds on activity) or understanding [8]. Unlike the laboratory works, hands-on activities do not necessarily need some special equipment and special medium.

Research studies showed that hands-on activities help students to improve understanding concepts resulting in better achievements and success in science subjects and to encourage their creativity in problem solving, promote student independence, improves skills such as specifically reading, arithmetic computation, and communication [8, 9]. [10] Emphasizes that children learn better when they can touch, feel, measure, manipulate, draw, and make charts, record data and when they find answers for themselves rather than being given the answer in a textbook or lecture.

For students to truly learn science concepts, they both need practical opportunities to apply knowledge and also need help in integrating or exchanging the knowledge they gain. According to the [11], students should have minds-on and/or heads-on experiences during hands-on activities. While doing hands-on activity, the learner is learning by doing but while minds-on learning, the learner is thinking about what she or he is learning and doing. [12], State that minds-on science activity includes the use of higher order thinking, such as problem solving compared to the hands-on activity. Therefore, students should be both physically and mentally engaged in activities that encourage learners to question and devise temporarily satisfactory answers to their questions [13].

As a result of incorrect informing from the environment, in Ethiopia, a lot of students think that science is complex, difficult and this affects their outlooks to science subjects in general and their achievement. For this reason, students' meeting science and liking science, improves positive attitudes towards science subjects. In the study area, Woldia full cycle primary schools, the method of teaching science, are associated with tremendous obstacles that inhibits effective way of teaching science. The researcher had the exposure to see the teaching method and the availability of laboratory during practicum supervision time and the school linkage program.

Therefore, the main purpose of this study is to assess the current status of hands-on (skill), minds-on (knowledge) and hearts on (attitude) activities in the study area, Woldia Town primary schools.

Statement of the problem

Science has become one of the most important disciplines in the school curriculum and its importance in general education has gained worldwide recognition [14]. The science laboratory has become a distinctive feature of science education.

Plainly the only way to learn about such remarkable kinds of action is to see the results by conducting experiments, and work in the laboratory [12]. To promote deep conceptual understanding (minds on), science skill (hands on) development, and positive attitudes toward science (hearts on), it is recommended that science teaching and learning should be focused on the use of scientific reasoning and experimental procedures to investigate real-life phenomena [15]. Hands on activities are variety of activities which allow students to handle, manipulate, and observe scientific processes. Such activities may or may not be done in actual laboratories and allows for learners to interact with materials and equipment (good article).

Despite the importance of attitude and incorporating hands on, minds on and hearts on activities in teaching science, there are tremendous obstacles to do these in Woldia Town primary schools. The researcher had the exposure to see the teaching method and the availability of laboratory during practicum supervision time and the school linkage program. The researcher also had the chance to talk with some science teachers and explore their ideas towards the attitude of the students about science subjects. These conditions initiated the researcher to conduct research to assess the status of hands on, minds on and hearts on activities in terms of the following research questions.

1. Do the students have positive attitudes towards science subjects?
2. Do teachers use different methods in teaching science that motivate the students' hands on, minds on and hearts on activity?
3. To what extent the schools' laboratory are available to encouraging students' hands on, minds on and hearts activities to the science subjects?

Operational definition

Hands on activity: it is a method of learning by doing. In science class it is defined as any science activity that allows the student to handle, manipulate or observe a scientific process to enhance critical thinking ability (psychomotor domain of learning).

Minds on activity: it is a mind-based activity associated with critical thinking ability of the students (cognitive domain of learning).

Hearts on activity: it is the activity associated with the feelings of the students (affective domain of learning).

METHODOLOGY

Design of the study

The main purpose of this study was to assess the status of hands on, minds on and hearts on activity of science subjects teaching in Woldia Town full cycle primary schools. In order to achieve the goal of this study, descriptive survey approach was used. Descriptive survey helps to have general understanding of the problem by studying the status of the problem.

Samples and Sampling Techniques

In Woldia Town there are eight full cycle primary government schools. Among these schools four government schools were selected using simple random sampling method and from these four school 425 students out of 3119 were selected as a source of information.

Data Collecting Tools

To obtain the necessary data, adapted closed ended questionnaire, unstructured interview and observational check list were developed and used.

Questionnaire: - Closed ended questionnaires were adapted with an English language and then translated into the local language, Amharic language, with the aid of two language college instructors to make effective and easy communication with participants [16]. And finally, the questionnaires were turned into English language to make easy for the scientific community. The questionnaire has four parts with a total of 47 items with four rating scale of matrix type. In that case strongly disagree is represented by 1, disagree is by 2, agree is by 3 and strongly agree is by 4. The researcher intentionally excluded the undecided option to motivate the student to decide.

Interview: unstructured interview was developed and provided for 4 laboratory assigned teachers.

Observation: the researcher did observation of laboratory rooms, students' activity so as to consume some information.

Validity and Reliability

The data collecting instruments were given for two college chemistry lecturers and two schoolteachers to check face validity and content validity against leading questions and few adjustments were done to increase the reliability of the questionnaire.

Data Treatment Techniques

The questionnaires obtained from the respondents were treated using Q-test in order to check whether any of the data was outlier or not. After collecting all the response of the respondent, the data was treated with Dioxin outliers. Among 425 responses of the student 12 responses were incomplete and 13 responses were rejected with Dioxin outliers using the following mathematical equations.

$$Q_{cal} = \frac{x_2 - x_1}{x_n - x_1}$$

where x_1= the smallest expected value (lower outlier)

and

X_2= next to the expected smallest value

$$Q_{cal} = \frac{x_n - x_{n-1}}{x_n - x_1}$$

X_n=the largest expected value (upper outlier)

Principally, $Q_{cal} > Q_{crt}(\alpha,v)$, the suspected outlier could be rejected while the $Q_{cal} < Q_{crt}(\alpha,v)$ the suspected outlier is retained. By this treatment 13 data were rejected and the rest 400 were retained at 95% confidence (i.e. at α value of 0.05) which makes response rate was 94.12%.

Data analysis techniques

To analyze the data both quantitative and qualitative techniques (mixed approach) were used. The quantitative analysis was used to assess the targeted variables using statistical tests /like percentage, mean / and the qualitative analysis, obtained from the interview and observation were narrated to triangulate the information gathered through questionnaire.

DATA ANALYSIS AND INTERPRETATIONS

In this part, results obtained from the questionnaires, observation and interviews were presented qualitatively and quantitatively. The data were analyzed using descriptive statistics (mean and percentage), graphs and tables.

Table 1

Students' Response about Their Attitudes towards Science Subject

Items	Strongly disagree		Disagree		Agree		Strongly agree		T
	Fre	%	Fre	%	Fre	%	Fre	%	F
I am happy during science class	15	3.75	46	11.5	185	46.25	154	38.5	4
I know the importance of science education	0	0	30	7.5	143	35.75	227	56.75	4
I love science teachers	78	19.5	76	19	107	26.75	139	34.75	4
I don't want to study science subjects(R)	138	34.5	105	26.3	141	35.25	16	4	4
The science in school is not related to my everyday life(R)	30	7.5	16	4	215	53.75	139	34.75	4
I understand the science concepts when science teacher teaching science	0	0	46	11.5	201	50.25	153	38.25	4
I am interested with science homework	15	3.75	92	23	153	38.25	140	35	4
Science teacher appreciate me when I did my tasks	41	10.25	46	11.5	168	42	145	36.25	4
I have a good understanding of basic concepts in science	122	30.5	46	11.5	154	38.5	78	19.5	4
I try to learn about science on my own.	141	35.25	106	26.5	78	19.5	75	18.75	4
Science classes have increased my interest in science	141	35.25	148	37	71	17.75	40	10	4
I am able to easily understand topics in science	202	50.5	78	19.5	75	18.75	45	11.25	4
I don't enjoy talking about science with my friends(R)	62	15.5	138	34.5	140	35	60	15	4
Grand Mean/average	**985**	**18.94**	**973**	**18.72**	**1831**	**35.21**	**1411**	**27.13**	**5**

R= Items that were reversely scored

Category type	**Disagree**	**Agree**
Grand mean/average	37.66%	62.34%

As it indicated in the above Table 1, most of the responses of the students indicated that their attitudes towards science subject is not far from the average. The mean percent for strongly agree is 27.13%, the mean percent for agree is 35.21%, which makes the aggregate agree category was 62.34%. The mean percent for disagree is 18.72% and the mean percent for strongly disagree is 18.94% which makes an aggregate category of disagree response was 37.66%.

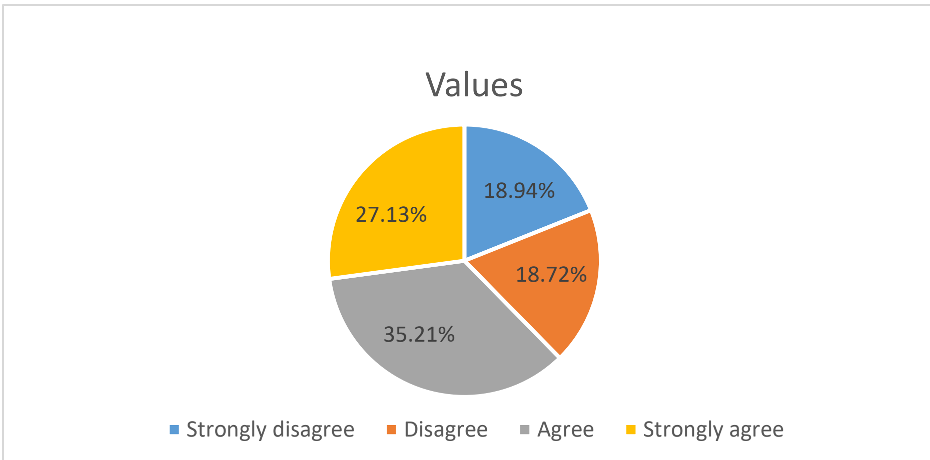

Figure 1. Students' Response about Their Attitude towards Science Subject.

The grand mean percent for the agree category is 62.34%, based on the question given to them, they react in satisfaction manner about their attitude of science subjects. The disagree category overall mean was 37.66%.

Table 2. *Students' Response about Method of Learning Science Subject*

Table 2.1. *Responses Related to Hands on Activity*

Items	Strongly disagree		disagree		Agree		Strongly disagree	
	Fre	%	Fre	%	Fre	%	Fre	%
1. During science class, we conduct different practical activities in groups	107	26.75	141	35.25	60	15	92	23
2. Classroom science teaching is mainly associated with practical activities	108	27	107	26.75	91	22.75	94	23.5
3. Science teacher motivated us to do different practical activities	120	30	108	27	126	31.5	46	11.5
4. I enjoy laboratory activities in science class	107	26.75	153	38.25	61	15.25	79	19.7
5. Our science teacher directed us to construct different activities from locally available materials	146	36.5	143	35.75	64	16	47	11.7
6. during science class different activities in the lab were done	62	15.5	91	22.75	125	31.25	122	30.5
7. I know how different activates can be done in the laboratory	192	48	118	28.5	69	17.25	24	6
8. Classroom Science teaching incorporate practical activity which makes me interested	122	30.5	46	11.5	154	38.5	78	19.5
9. Science teachers rely primarily on lectures as a teaching method(R)	158	39.5	123	30.75	59	14.75	60	15
Grand mean/average	**1202**	**33.39**	**1027**	**28.53**	**783**	**21.75**	**588**	**16.3**

R= items that were reversely scored

Category type	Disagree	Agree
Grand mean/percentage	61.92%	38.08%

The grand mean percent for the agree category is 38.08% while the disagree category overall mean was 50. 79%.

Table 2.2. *Students' Response Related to Their* ***Hearts on*** *Activity*

Items	Strongly disagree		Disagree		Agree		Strongly disagree	
	Fre	**%**	**Fre**	**%**	**Fre**	**%**	**Fre**	**%**
1. Science is too complicated for most students to understand.	63	15.75	77	19.25	152	38	108	27
2. I learn science **best** when I can do labs or activities.	45	11.25	45	11.25	139	34.75	171	42.7
3. The science in school is not related to my everyday life(R)	108	27	92	23	62	15.5	138	34.5
4. I like to share what I've learned in science class with my friends or family.	62	15.5	91	22.75	125	31.25	122	30.5
5. I enjoy learning science with practical activities	110	27.5	139	34.75	91	22.75	60	15
6. I am happy with my science teacher because he/she focused on theoretical concepts rather than practical activities	62	15.5	138	34.5	140	35	60	15
7. Science teacher motivated us to use locally available materials to conduct simple experiments	106	26.5	92	23	124	31	78	19.5
8. I do not enjoy doing labs in my science class(R)	171	42.75	145	36.25	39	9.75	45	11.2
9. I am learning science only with taking notes which makes me board	30	7.5	16	4	215	53.75	139	34.7
Grand mean	757	21.03	835	23.19	1087	30.19	921	25.5

Category type	Disagree	Agree
Grand mean/percentage	44.22%	55.78%

The grand mean percent for the agree category is 55.78%, while the disagree category overall mean was 44.22%.

Table 2.3. *Students' Response Related to Minds on Activity*

Minds on activity	Strongly disagree		Disagree		Agree		Strongly disagree	
	Fre	**%**	**Fre**	**%**	**Fre**	**%**	**Fre**	**%**
1. I am learning science by taking note from the textbook	169	42.25	77	19.25	61	15.25	93	23.2
2. I am learning science by taking note from the blackboard	77	19.25	63	15.75	152	38	108	27
3. Class work, group work and homework are usually given us in science subjects.	110	27.5	139	34.75	91	22.75	60	15
4. Teachers briefly discussed science concepts during the teaching-learning process	45	11.25	45	11.25	139	34.75	171	42.7
5. During science class brainstorming approach helps us to analyze the science concepts	92	23	61	15.25	139	34.75	108	27
6. science teacher designed different teaching method to increase the students understanding	124	31	77	19.25	61	15.25	138	34.5
7. Learning things in science is easy for me	108	27	92	23	62	15.5	138	34.5
8. I have low understanding with science subjects' laboratory activities	108	27	92	23	61	15.25	139	34.7
9. We learnt science without the aid of laboratory activities	92	23	30	7.5	108	27	170	42.5
Grand mean	**925**	**23.62**	**676**	**18.72**	**874**	**25.41**	**1125**	**32.2**

Category type	Disagree	Agree
Grand mean/percentage	42.34%	57.66%

The grand mean percent for the agree category is 57.66%, while the disagree category overall mean was 42. 34%.

Summary table

Activity type	Disagree	Agree
Hands on	61.92%	38.08%
Minds on	42.34%	57.68%
Hearts on	44.22%	55.78%
Grand mean/average	49.49%	50.51%

Table 3. Students' Response Related to School laboratory for learning science

Items	Strongly disagree		disagree		Agree		Strongly disagree	
	Fre	%	Fre	%	Fre	%	Fre	%
The school has laboratory facilities to support the teaching of science subjects	107	26.75	141	35.25	60	15	92	23
The school laboratories have chemicals and apparatus	161	40.25	107	26.75	85	21.25	47	11.7
There is no Basic Science laboratory in the school(**R**)	45	11.25	32	8	200	50	123	30.7
We are engaged in the laboratory by our teachers	107	26.75	153	38.25	61	15.25	79	19.7
The teachers carried out different activities using locally available materials in the lab	30	7.5	16	4	215	53.75	139	34.7
In each science subject, we do have lab session at least one period per week	196	49	97	24.25	61	15.25	46	11.5
The lack of chemicals and apparatus affected us to conduct practical activities	107	26.75	153	38.25	61	15.25	79	19.7
Grand mean	843	30.67	699	23.25	703	26.79	555	19.2

R*= Items reversely scored*

Category type	Disagree	Agree
Grand mean/percentage	53.92%	46.08%

The grand mean percent for the agree category is 46.08% (1258 response out of 2800 responses) while the disagree category overall mean was 53.92% (1542 responses out of 2800 responses).

Result obtained from the observation and unstructured interview

The result obtained from these instruments were mainly the following: the students do not strong positive attitude towards the science subjects, the schools don't have adequate laboratory, even though the schools assigned laboratory rooms without any standard there were not appropriate chemicals and apparatuses, the inadequacy of laboratory affects the teaching-learning process by dispassionate both the teachers and the students to do hands on, minds on and hearts on activities.

DISCUSSIONS

The first research question was answered by analyzing the students' response given in Table 1. As it indicated in the table, most of the responses for the attitude of the students towards science subject are not far from the average. Research indicated that students' attitude and academic achievement exerts a strong relationship, the existence of positive attitudes enhanced the academic achievements of the students [17]. According to [18], there are stronger relationships between the variables of positive attitude towards science and students results as plausible values of science. As the results of this study indicated that, in the study area only 64.7% of the students have positive attitude towards science subject and the rest 35.3% do not have positive attitudes towards the science subject which in turn affects the overall achievements science subjects.

The second research question was answered by interpreting the students' response given in Table 2. The second questions invite to explore hands on, hearts on and minds on activities which were indicated in Table 2.1, 2.2 and 2.3. As the results depicted in the Table 2.1, most of the responses of the students for the method of learning science subjects were below the average. In the absence of differentiated teaching method, the achievements of the students could be delayed even that would leads to below standard results. A physics metaphor described law of motion from an educationists' perspective as,

"A body at rest tends to remain at rest; a body in motion remains in motion and the brain usually follows".

Another study indicated that science subject achievements can be improved by incorporating hands on activities which enhances the skill of inquiry [19]. [20] Described that 'stimulating curiosity to enhance learning' highlight that curiosity combined with the motivation to learn is more important than intelligence. Students' curious mind fosters the learning of abstract and complex concepts. Curiosity as a desire for active learning, spontaneous exploration, and find out something which is new. The basic role of curiosity in learning is to encourage and create knowledge [21]. In teaching science hands on, minds on and hearts on activity increases the students' curiosity which leads the students' maturity for the required level. But the results of this study revealed that the teaching methods for science subject were not included the basic concepts of science teaching to motivate the students to be curios and passionate towards the science subject. …

According to [22], hands-on activities are based on the use of everyday gadget, simple set-ups or low-cost items that can be found and assembled very easily. But as we have seen from the result the students' learning style is not attractive with relative to the need of science education. According to [23], one of the aims of science education is used to develop students understanding of the method by which knowledge has been gained, appropriate skill has been developed. Practical work is an essential component of science teaching and learning both for developing students' knowledge about science and developing scientific knowledge.

Regarding to the third research question, table 3 showed that the findings of the study based on the assessments of the availability of science laboratory to help the students learning. As the result vividly indicated that schools found in the study area do not have adequate laboratory to facilitate the teaching process of science subjects and the students do not have the chance to practice hands on activities to engage knowledge about science subjects.

SUMMARY, CONCLUSION, AND RECOMMENDATION

Summary and conclusion

The purpose of this study was to assess the current statues of hands on, minds on and hearts on activities in Woldia Town full cycle primary schools using descriptive survey approach research method. To achieve this purpose, the research questions were:

1. Do students have positive attitude towards science subjects?
2. Do teachers used different methods in teaching science that develop the students' hands on, minds on and hearts on activities?
3. To what extent the schools' laboratory encouraging teaching science subjects?

To answer these research questions descriptive survey research type was used, and the data were collected through questionnaire, observation, and unstructured interview. The data obtained through these tools were organized and analyzed using quantitative, percentage and mean, and qualitative, narrative, techniques. The analyses revealed the following results:

1. Most of the students were do not have positive attitude towards science subjects
2. The methods of teaching science subject do not exercised hands on, minds on and hearts on activities during science session.
3. Schools in the town have lack of adequate laboratory rooms, chemicals and apparatus in the schools.

Based on the finding the researcher concluded that the method of teaching science subjects in the school found in Woldia Town full cycle primary schools was mainly theoretical. But according to [22], teaching of must include practical activities like hands on activity, to motivate the students' attitude towards science subject and increases their curiosity to develop their scientific knowledge.

Recommendation

Based on the conclusion drawn from the findings, the researcher try to forward the following recommendation: As the mean result indicated, the method of teaching science subject were unsatisfactory, it lacks hands on, minds on and hearts on activity in order to engage students' academic knowledge. So, the school science teachers, school principals, district education office heads should supervise the teaching system and must give remedial action to help students to engage scientific knowledge. Specially, the subject teacher should be dedicative, willing to include/inculcate/ hands on, minds on and hearts on activity in their day today teaching learning process.

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ASSESSMENT OF ARSENIC, CADMIUM AND LEAD IN SNUFF IN THE ASHANTI REGION OF GHANA

Owusu-Asante, O. J.[1], Mensah, P.[1] Duah-Gyamfi, A.[1], Owusu, J.[1], Minkah, E.[1], Wumbeidow, H.[1], Ibrahim, S.[1], Ofori, E.[1], Nyarko, D. E[1].
[1]CSIR-Forestry Research Institute of Ghana, P. O. Box UP 63, Kumasi, Ghana
Corresponding Author Email: jowusu-asante@csir-forig.org.gh

ABSTRACT

Tobacco snuff usually comes from *Nicotiana tabacum* in the wet or the dry form. The leaves are finely ground either by pounding or crushing and sometimes may be contaminated with heavy metals such as Lead (Pb), Cadmium (Cd) and Arsenic (As) which can accumulate in the body following prolonged use resulting in adverse health conditions. The objectives of this study are to determine the presence of heavy metals (Pb, Cd and As) in different tobacco snuff from selected transport terminals in the Ashanti Region of Ghana and to compare the acceptable daily intake with permissible limits by the Food and Agricultural Organization/World Health Organization (FAO/WHO) recommendation. Three transport terminals (the Kumasi Metropolis, Ejisu and Offinso districts) in the Ashanti Region were randomly sampled for tobacco snuff. Snuff samples/brands from the different stations were subsequently sent to the laboratory for analysis. The wet acid digestion method was used to determine the concentration of Pb, Cd and As of each sample using the atomic absorption spectrophotometer. The study found 18 snuff samples common among the transport terminals within the Ashanti Region. The 18 snuff samples had significant levels of metals in the range: Lead (0.298- 0.533 μg/g), Cadmium (0.977- 1.947 μg/g) and Arsenic (0.071 - 1.011 μg/g). The acceptable daily intake of heavy metals from most of the samples was above the maximum permissible limit accepted by the Food and Agriculture Organization and World Health Organization. The results of this study showed that snuff contains toxic heavy metals that may cause health problems. Therefore, urgent regulation of the product is needed alongside an educative campaign to create awareness about the health implications associated with snuff. *[African Journal of Chemical Education—AJCE 12(2), July 2022]*

INTRODUCTION

Nicotiana tabacum is commonly referred to as tobacco. The leaves are smoked, chewed or sniffed either as a depressant or to induce sneezing during periods of lightheadedness or slight dizziness. *Nicotiana tabacum* is also popular for its cultural and traditional purposes [1]; [2]. Tobacco snuff usually comes in the wet or the dry form. Based on the quantity of the leaves and preference, the leaves are finely ground either by using the local way of pounding (mortar and pestle) or the grinding stone [3]. Thereafter, it is mixed with additives like flavors such as peppermint and eucalyptus oil, menthol or fruit extracts [4]. In Ghana, the main additive used is the saltpetre. In the dry form, snuff is sniffed or swallowed whereas in the wet form, the snuff is placed between the lower gum and the cheeks and mixed with saliva to aid in the release of nicotine into the mouth and body [5]. Through these assimilation processes, toxic metals may enter the body.

Research has shown that carcinogenic agents and toxic heavy metals such as Cadmium (Cd), Lead (Pb), Arsenic (As) could be present in the tobacco snuff as they are absorbed by the leaves during growth [6]. Some of these heavy metals are required in minute quantities in the function of plants and animals [7]. In higher concentrations, these heavy metals bioaccumulate and pose severe health effects such as anemia, kidney failure, irritability, coma and death in humans [8]. Heavy metals such as As, Cd and Pb are carcinogenic and may pose severe health risks in tobacco products [9]. As and Cd are known for causing lung injury [10]. Cd and Pb are of concern since they can be stored in the body for long and stimulate tissues to immune response, cell injury and tissue repair processes [11]. Cd exposure can cause cataract in the lens of the eye upon accumulation, can affect the kidney, the nervous system and the reproductive system [12]; [2]. Lead is particularly known to decrease the intelligence quotient levels especially in younger children and can cause an irreversible brain damage [1]; [13]. Aside being carcinogenic, Arsenic in the human body can cause skin pigmentation problems, ulcerations of the mouth, low haemoglobin, leukemia, acute renal failure, seizures and nerve damage [14]; [1].

According to the World Health Organization (WHO) International Agency for Research in Cancer (IARC), Smokeless Tobacco Products (STPs) such as snuff has been classified as Group 1, Group 2A and Group 2B carcinogens. Group 1 carcinogens are definitely carcinogenic to humans while Group 2A and Group 2B are probably carcinogenic and possibly carcinogenic to humans, respectively [12]; [15].

In Ghana over the past few years, local snuff use has received high patronage despite the health risks posed to sniffers. This patronage is common around transport terminals where different snuff brands are sold to commuters travelling to different parts of the country. Smokers or sniffers have been shown to be more highly exposed to As, Cd and Pb [11] however, Pb, Cd and As are more poisonous even at lower levels than Ni [9].

The overall goal of this research is to create awareness among those who patronize snuff and the general public at large about the dangers posed by the presence of potential heavy metals in snuff. Therefore, in this study, we determined the levels of Cd, Pb and As as well as the acceptable daily intake of these toxic metals in snuff obtained from transport terminals in the Ashanti Region of Ghana.

METHODOLOGY

Sample Collection

Three transport terminals (Kumasi Metropolis (6.7252° N, 1.6566° W); (Ejisu District (6.7151° N, 1.5091° W) and Offinso districts (7.3049° N, 1.7928° W) in the Ashanti region of Ghana were randomly selected for this study (Figure 1). The terminals are among the busiest and serve as the exit terminals between the Ashanti region and other regions of Ghana. Eighteen samples of tobacco snuff were randomly obtained from the transport terminals in November 2019. The names of the local manufacturer or snuff brand were noted and coded for further analysis.

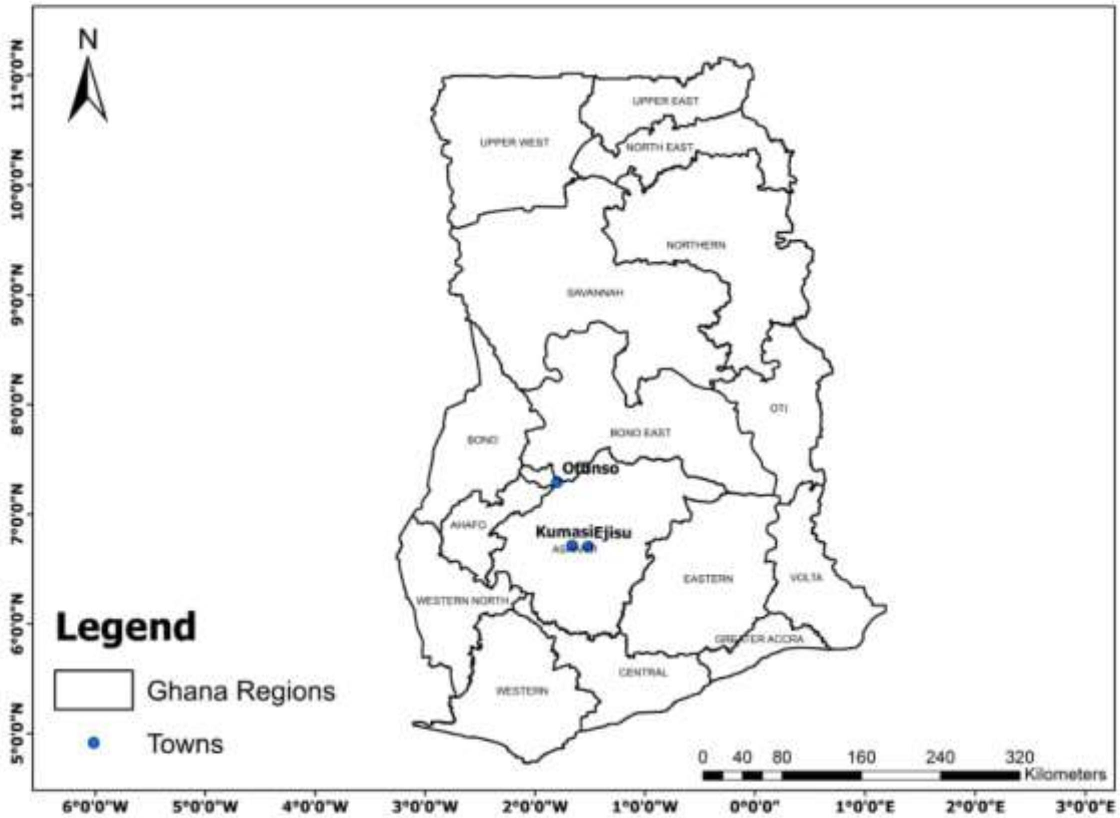

Figure 1: Ghana Regions

Sample Pretreatment

All samples purchased were kept in separate zip lock bags, sealed, and subsequently sent to the laboratory for analysis. Samples not in powdery form were ground, sieved and stored. One gram of each sample was weighed using an electronic balance (Mettler-Toledo Ltd, PM 4000) and used for further analysis as per the standard procedures given below for the different metals.

Sample Digestion

Each of the 1g snuff sample was poured into a Kjeldahl digestion tube. Perchloric ($HClO_4$), Nitric acid (HNO_3) and Hydrochloric acid (HCl) were added in the ratio of 1:2:3. The mixture was then digested at a temperature of 450 ^{0}C until complete digestion for about 30 to 60 minutes [16].

Sample Analysis

After digestion was complete, the mixture was decanted into a 100 ml volumetric flask and the solution was topped up to the 100 ml mark. This digest was used to analyze all the metals (Pb, As, Cd). The unknown concentration of this solution was then read using an atomic absorption spectrophotometer (AAS) (Buck Scientific Inc, 210 VGP) for the various metals at specified wavelengths [16]; [17].

Instrumentation

The basic setup (air pressure,50 – 60 psi; acetylene pressure, 10 -15 psi; voltage, 208 – 240V) of the AAS was ensured. The file for the type of analysis and hollow cathode lamps were selected with appropriate wavelengths – Pb at 283.31 nm, Cd at 228.80 nm, As at 193.70 nm. A calibration curve was plotted for each of the elements to be analyzed from the stock standards (Buck Scientific).

The prepared sample solution digest was analyzed for the elements. The total concentration of the element in the sample solution (100 ml) was calculated by multiplying the concentration in mg/L by 0.1L. This gave the total mass of the element in solution [17]**.** The percentage amount of the element was found by dividing the mass of the element in solution by initial amount of sample taken followed by a multiplication by 100 (Eqn 1)

$$\text{Conc. } (H_m) \text{ (mg/kg)} = \frac{\text{Conc. from AAS X Nominal volume}}{\text{Sample weight (g)}} \qquad (1)$$

Where, H_m = heavy metal, Nominal volume =100 ml, Sample weight = 1.00g

Data Analysis

A one-way Analysis of Variance (ANOVA) was used to examine differences in concentration of each of the heavy metals among the snuff brands. Prior to ANOVA, data was examined for normality using the Kolmogorov Smirnov test, and homogeneity of variance using the Levene test. Microsoft excel was used to generate graphs of means concentrations of heavy metals among the snuff brands.

RESULTS AND DISCUSSION

The concentration of each heavy metal in the snuff samples was shown in figures 1, 2 and 3. The results were reported as the mean ± standard deviation for each metal. Based on figure 1, the highest concentration of Pb was found in sample SPS at 0.533 ± 0.017 μg/g. Lead is known to be one of the non-essential metals that are highly toxic and can cause cancer even in small concentrations [18]. The highest concentration of As and Cd in snuff samples were also shown in figures 2 and 3 as 1.011 ± 0.053 μg/g and 1.947 ± 0.100 μg/g respectively. Cadmium was shown at the highest concentration at 1.947 ± 0.100 μg/g in sample OPS whilst Arsenic occurred in sample HAS at the highest concentration of 1.011 ± 0.053 μg/g.

The concentration of heavy metals in brand MS ranged from 1.540 ± 0.069 μg/g to 0.459 ± 0.008 μg/g. Cd recorded the highest concentration followed by As and then Pb. OPS had concentrations of the heavy metals ranging from 1.947 ± 0.100 μg/g for Cd to 0.367 ± 0.017 μg/g for Pb. Cd>As> Pb was the observed pattern. The concentration of heavy metals in brand HMS ranged from 1.347 ± 0.108 μg/g to 0.292 ± 0.032 μg/g. Cd recorded the highest concentration followed by As and then Pb. The three heavy metals occurred in the order Cd>Pb>As. The concentration of heavy metals in brand AMS ranged from 1.353 ± 0.190 μg/g to 0.367 ± 0.008 μg/g. Cd recorded the highest concentration followed by As and then Pb. The three heavy metals occurred in the order Cd>As>Pb. The concentration of heavy metals in brand NMS ranged from Cd (1.253 ± 0.072) μg/g. to As (0.298 ± 0.013) μg/g.

The concentration of heavy metals in brand HAS ranged from 1.200 ± 0.132 μg/g to 0.362 ± 0.017 μg/g Cd recorded the highest concentration followed by As and then Pb. The concentration of heavy metals in brand KSS ranged from 1.370 ± 0.098 μg/g for Cd to 0.436 ± 0.013 μg/g for Pb.

The concentration of heavy metals in brand TKS ranged from 1.530 ± 0.203 µg/g to 0.115 ± 0.068 µg/g. Cd recorded the highest concentration followed by Pb and then As. The three heavy metals occurred in the order Cd>Pb>As. SMS had concentration of metals in the range from 1.180 ± 0.253 µg/g to 0.426 ± 0.024 µg/g. Cd recorded the highest concentration followed by As and then Pb. The concentration of heavy metals in brand NRS ranged from 1.003 ± 0.159 µg/g to 0.381 ± 0.025 µg/g Cd recorded the highest concentration followed by As and then Pb. KS had concentration of heavy metals in the range from 1.317 ± 0.234 µg/g to 0.445 ± 0.013 µg/g Cd recorded the highest concentration followed by As and then Pb.

The concentration of heavy metals in brand VS ranged from 1.343 ± 0.372 µg/g to 0.309 ± 0.017 µg/g Cd recorded the highest concentration followed by As and then Pb. The concentration of heavy metals in brand UYS ranged from 1.473 ± 0.493 µg/g to 0.370 ± 0.021 µg/g Cd recorded the highest concentration followed by As and then Pb. The three heavy metals occurred in the order Cd>As>Pb.

The concentration of heavy metals in brand UBWS ranged from 1.220 ± 0.306 µg/g to 0.434 ± 0.017 µg/g. The three heavy metals occurred in the order Cd>As>Pb. The concentration of heavy metals in brand UABS ranged from 0.977 ± 0.099 µg/g to 0.365 ± 0.013 µg/g. Cd recorded the highest concentration followed by As and then Pb. The three heavy metals occurred in the order Cd>As>Pb. The concentration of heavy metals in brand SPS ranged from 1.480 ± 0.207 µg/g to 0.071 ± 0.011 µg/g. Cd recorded the highest concentration followed by Pb and then As. Brand PS concentration of heavy metals in brand PS ranged from 1.233 ± 0.085 μg/g to 0.456 ± 0.025 μg/g Cd recorded the highest concentration followed by As and then Pb. Finally, the concentration of heavy metals in brand OS which is the last brand ranged from 0.599 ± 0.027 μg/g to 0.396 ± 0.004 μg/g This brand followed a usual pattern unlike the rest. Arsenic recorded the highest concentration followed by Cd and then Pb. The three heavy metals occurred in the order As>Cd>Pb.

The concentration of Pb in the 18 snuff brands ranged from 0.533 ± 0.017μg/g to 0.298 ± 0.013 μg/g to Local snuff brand SPS recorded the highest whilst brand NMS recorded the least. Fig 1 gives the concentration of Pb in the 18 snuff brands There was a significant difference ($P < 0.05$) in the concentration of Pb among the 18 local snuff brands examined. This was similar to the lead concentration with a range from 0.28 ± 0.03 μg/g to 0.85 ± 0.01 μg/g [(Pappas *et al.*, 2008) during the analysis of toxic metals in commercial moist snuff and Alaskan iqmik. [8] published concentrations of lead in 30 samples of tobacco (*Nicotiana tabaccum*) snuff in Nigeria. The concentration of lead in the tobacco snuff samples in Nigeria ranged from 0.41 to 1.13 μg/g for north central, 0.45 to 2.48 μg/g for southwest, 0.01 to 1.48 μg/g for southeast, and 0.02 to 1.16 for northwest. These values were within the range of this study except the values were higher than that of the study. [1] had 0.03–68 μg/g at its range for Lead the study of toxic metals in snuff samples in India. The upper limit of 68 μg/g was far above that of the current investigation.

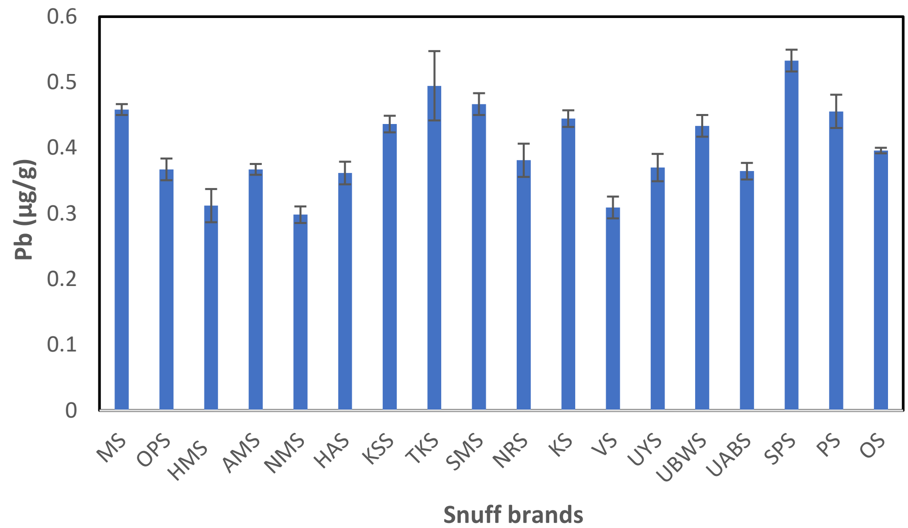

Fig 1: Concentration of Pb in the 18 snuff brands

As recorded its concentration in the range of 1.011 ± 0.053 µg/g to 0.071 ± 0.011 µg/g as shown in Fig 2. HAS had the highest concentration of As whilst SPS had the lowest concentration of As. There was a significant difference ($P < 0.05$) in the concentration of As among the 18 local snuff brands examined. These values were lower compared to what [19] reported for the mineral profiling in Ghanaian local snuff and imported snuff in the range of 0.862 µg/g to 1.93 µg/g.

[1] determined toxic metals in Indian smokeless tobacco products. Levels of Arsenic in the smokeless tobacco products were (0.1–3.5 µg/g) and these values were in the range of the lower limits and higher than the upper limits of the study. The levels of Arsenic recorded by [20] in the

analysis of commercial moist snuff were in the ranges 0.13 ± 0.01 μg/g and 0.36 ± 0.06 μg/g. The lower limits found in [20] was higher than that of the study but the upper limit was lower than that of the present study.

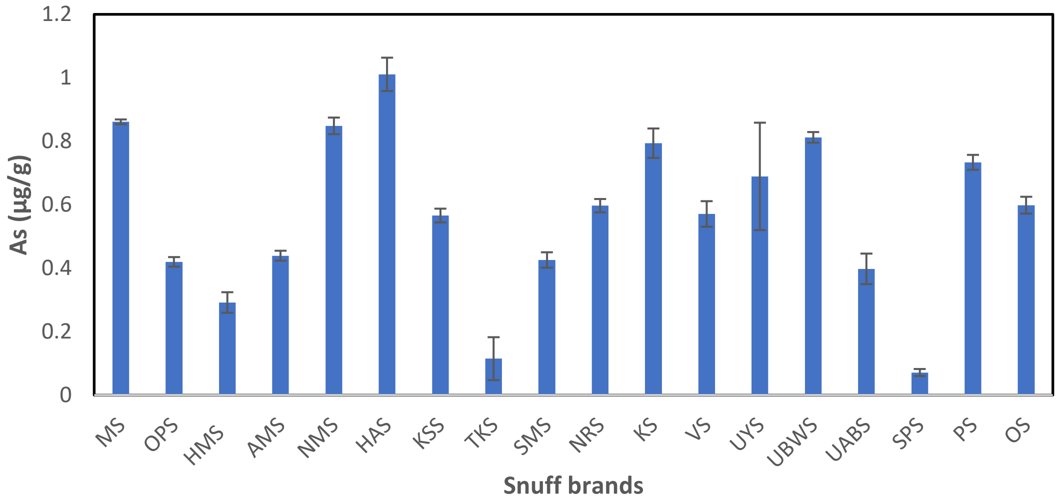

Fig 2: Concentration of As in the 18 snuff brands

The concentration of Cd in the 18 snuff brands ranged from 1.947 ± 0.100 µg/g to 0.417± 0.032 µg/g as shown in Fig 3. Local snuff brand OPS recorded the highest whilst brand OS recorded the least. There was a significant difference ($P < 0.05$) in the concentration of Cd among the 18 local snuff brands examined. [1] had 0.01–3.2 µg/g as its range for Cadmium during the study of toxic metals in snuff samples in India. The lower limit from [1] of 0.01 µg/g was lower than 0.977 µg/g. However, the upper limit of 3.2 µg/g from [1] was far higher than that of 1.947 µg/g obtained from the current study.

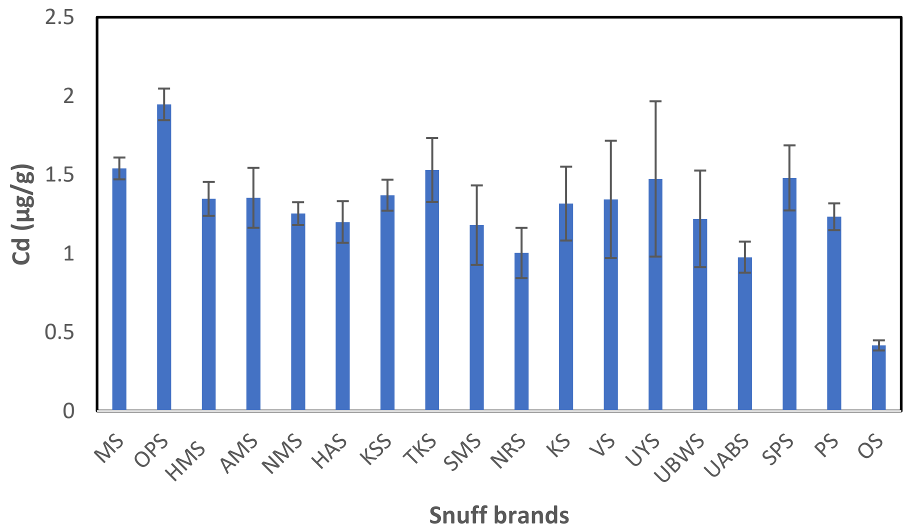

Fig 3: Concentration of Cd in the 18 snuff brands

Acceptable Daily Intake

Acceptable Daily Intake (ADI) is the amount of a substance, expressed on a body-mass basis, daily ingested in food or drinking water over lifetime without imposing any appreciable risk to human health [21]. Table 2 gives the permissible intake levels of Pb, Cd and As.

According to [1] (Dhaware *et al* ., 2009)**,** the daily intake was calculated by the equation below:

$$DI\ (\mu g/day) = C_{metal} \times W_{analyses} \times D_{intake} \qquad (2)$$

Where C_{metal} = concentration of the metal in the snuff sample taken for analysis.

$W_{analyses}$ = weight of the sample taken for analysis (1 g in this study)

D_{intake} = daily intake of pouch (10 pouches a day)

Table 2: Acceptable daily intake of Pb, As and Cd

Sample 1D	ADE of Pb/ (µg/day)	ADE of As/ (µg/day)	ADE of Cd/ (µg/day)
MS	4.59	8.61	15.40
OPS	3.67	4.20	19.47
HMS	3.12	2.92	13.47
AMS	3.67	4.39	13.53
NMS	2.98	8.49	12.53
HAS	3.62	10.11	12.00
KSS	4.36	5.66	13.70
TKS	4.94	1.15	15.30
SMS	4.67	4.26	11.80
NRS	3.81	5.97	10.03
KS	4.45	7.94	13.17
VS	3.09	5.71	13.43
UYS	3.70	6.89	14.73
UBWS	4.34	8.12	12.20
UABS	3.65	3.98	9.77
SPS	5.33	0.71	14.80
PS	4.56	7.33	12.33
OS	3.96	5.99	4.17

Comparison of the Acceptable daily intake of Pb, As and Cd to the WHO permissible limits

The ADI of all the metals detected in all brands (Table 2) were compared with Permissible Intake Levels as per FAO/WHO Recommendations (Table 3) to ensure the safety of the snuff for consumer use.

Table 3: Permissible Intake Levels as per FAO/WHO Recommendations [1]

Metal	**Provisional Tolerable Weekly Intake (µg/kg/week**	**Per Day Intake (µg/kg/day)**	**For a 60-kg Individual (µg/day)**	**Ref**
Pb	25	5	300	FAO/WHO
As	15	3	180	FAO/WHO
Cd	3.5	0.2-1	30	WHO/JECFA

From Table 3 the daily recommended intake for Lead is 5 µg/kg/day. 17 samples were within the permissible limit except for sample SPS which had an ADI of 5.33. However, a continuous use of the smokeless tobacco could result in bioaccumulation of lead with its negative health effects such as abdominal pain, headache, anemia, irritability, kidney failure [8] and negative effects on the hematic and the immune system [1]. According to the Joint FAO/WHO Expert Committee on Food Additives (JECFA), the accumulation of lead in the body was based on its net absorption which comprises of 40% from dietary sources, 10% from food and drinking water, and up to 50% from inhalation of lead compounds. This means that at an intake of 5 µg/kg bw/day, retention of leas in the body leads to an increased blood lead level [13].

In the case or Arsenic, most of the levels were above the permissible intake levels. Out of 18 snuff samples, only three samples (HMS, TKS and SPS) had permissible limits of 2.92 µg/day, 1.15 µg/day and 0.71 µg/day respectively that were lower than the FAO/WHO acceptable limit of 3 µg/kg/day. All the 15 samples were above the permissible limits.

From table 3, it was observed that all the 18 snuff samples were far above the permissible limits of **0.2**-1 µg/kg/day as set by the WHO/JECFA for Cadmium.

CONCLUSION

In summary, the 18 snuff brands tested had significant levels of metals as compared to other groups of smokeless tobacco in the range: Pb (0.298- 0.533 µg/g), Cd (0.977- 1.947 µg/g) and As (0.071 - 1.011 µg/g). This study emphasizes the acceptable daily intake of these toxic heavy metals. In the case of Pb, all 17 samples were within the permissible limits of the WHO with the exception of only 1 sample which was higher than the permissible levels. For Cd, almost all their samples were above the permissible limits of the WHO while As had only three samples in the permissible limits of WHO. Further, the acceptable daily intake of the tested metals exceeded the allowable safe limits recommended by the FAO and the WHO. This poses a high risk to consumers as they could develop harmful health effects. It is therefore recommended that the sale of the snuff be regulated in these transport terminals.

In addition, educative programs aimed at awareness creation among the youth and patronizes of snuff especially drivers be implemented to sensitize them on the dangers associated with snuff. Further research and screening of snuff and other local products (e.g., lipstick) displayed on the market for the presence of heavy metals and poisonous substances need urgent attention and consideration.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest regarding the publication of this paper.

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IN-SERVICE CHEMISTRY TEACHERS' REFLECTIONS ON AND EXPERIENCES WITH SUPERVISED LABORATORY INSTRUCTION IN ETHIOPIA

Mirtachew Tihar Ali and Annette Lykknes
Department of Teacher Education, NTNU−Norwegian University of Science and Technology, Norway.
Corresponding Email: mirtachew.t.ali@ntnu.no; mfedlu94@gmail.com

ABSTRACT

This qualitative study reports on 12 in-service teachers' reflections on and experiences with supervised laboratory instruction (SLI) based on a two-day professional development workshop. Three main themes emerged from thematic analysis of the interview transcripts: (1) SLI is an attractive teaching method, (2) SLI is challenging to implement in the classroom and (3) teachers need support to teach SLI. Attractive features of SLI included pre-laboratory activities, reflective group discussions, and scaffolding that could help them accomplish difficult laboratory tasks. However, teachers felt limited by an overloaded curriculum, little time, and a lack of lab facilities, self-confidence, and experimental experience. To implement SLI in their own classrooms, the teachers expressed the need to receive support from university staff through regular in-service laboratory training and inspirational scientific discourses. Furthermore, they emphasized the importance of access to SLI-adapted teaching materials and qualified laboratory assistants. Overall, teachers found SLI quite beneficial to their laboratory teaching in high school chemistry education. *[African Journal of Chemical Education—AJCE 12(2), July 2022]*

INTRODUCTION

Teaching science without laboratory activities—engaging tasks that learners perform by manipulating equipment and materials in a laboratory or another environment to observe and understand the natural world—is almost unimaginable. Indeed, laboratory instruction has been an integral part of science curricula at various levels for over a century [1-2]. The benefits of engaging students in laboratory activities include the potential to develop conceptual knowledge, enhanced understanding of the complexities and ambiguities of science, problem-solving skills and practical skills, an increased interest in science, and teamwork skills [1, 3-4]. Laboratory activities could potentially also enhance positive social relationships among students [5].

The use of laboratory activities in chemistry is less common in developing countries such as Ethiopia—despite the call for laboratory-based instruction in the Ethiopian science curriculum [4, 6]. The main reasons for this are a shortage of laboratory space and facilities, lack of time, few trained technicians, fear of chemical hazards, poor preparation of teachers, lack of confidence, absence of quality curriculum materials, overloaded curricula and large class sizes, and lack of student-centered teaching methods [4, 7-8]. Indeed, the so-called Ethiopian Education Development Roadmap (2018–30) initiative, launched by the Ethiopian Ministry of Education [9, p. 23–26], argues that previous efforts to improve STEM (Science, Technology, Engineering & Mathematics) teaching have failed due to an exaggerated emphasis on school buildings and facilities, such as instructional satellite televisions, over learning outcomes as well as the use of uninspired curriculum materials that are disconnected from the world of work. The 2018 roadmap recommends, among other things, that the high school science curriculum foster practical skills, scientific inquiry skills, and innovative and critical thinking skills, all of which might be developed as part of well-planned laboratory activities. A remarkable annual real GDP growth (6.1% in 2019/20) has indeed made it feasible to invest in science education at the secondary school level in the country and at the regional level [10]. To this end, the Ethiopian government has implemented a so-called 70:30 policy through which 70% of the enrolled students would be in STEM subjects [11].

The overarching goal of the project to which this study belongs is to help Ethiopian chemistry teachers implement meaningful laboratory instruction in their classrooms. For this purpose, we have developed a laboratory instruction pedagogy (introduced below), applied it to selected chemical experiments, and tested it on teachers who attended a professional development workshop. By training teachers in this pedagogy and analyzing their reflections and experiences in learning from, and practicing it, we aimed to contribute to the understanding of how laboratory instruction can be taught in an Ethiopian context.

Professional development for laboratory teaching and learning

Well-designed professional development (PD) programs are considered to be crucial to transforming schools and improving students' academic achievements [12-13]. To promote the quality of school learning, however, teachers' PD experiences must result in effective teaching practice [14]. This could be achieved by training teachers in conceptual understanding and practical work and by establishing a culture of shared responsibility to support students' learning—like a professional learning community [15].

However, a change in active learning instructional strategies takes time and requires material resources, such as well-developed curriculum materials; it might also involve school incentives, such as reduced teaching loads or financial benefits [16-17]. Teachers may also have difficulties translating new insights into their school settings [13]. For teachers in African countries, their lack of training in laboratory experimentation constitutes an additional challenge in implementing active learning practical laboratory work in their classrooms [4, 8]. [18], however, revealed that when teachers take time to try out active learning pedagogies in which they can learn about and try out experiments, there is a high chance of changing their traditional teaching practice.

The workshop that we designed for this study was organized as one such PD activity in which teachers could get practical experience both in doing laboratory experiments in the classroom and in practicing a new instructional pedagogy and discussing it and sharing experiences in groups of peers. To this end, based on research on factors that could contribute to learning through laboratory instruction, we developed a pedagogy hereafter referred to as supervised laboratory instruction (SLI).

Supervised laboratory instruction (SLI) and meaningful learning

SLI is a learner-centered laboratory instructional pedagogy which emphasizes learning through social interaction in groups and for which sufficient scaffolding [19-20] to actively engage learners in hands-on and minds-on activities [21] and promote learning is considered pivotal [22]. To further benefit students' learning in the laboratory, on the recommendation of [23], pre-laboratory activities have been included as well.

In SLI, like in inquiry-based teaching, the teacher takes the role of facilitator, who assists the students to process the information and coach their actions [24]. Teachers' scaffolding help focus learners' attention toward the learning outcomes, simplify the learning activities, model and demonstrate, and prompt ongoing evaluation and assessment of learning [19-20, 23]. In sum, the following three main features characterize SLI pedagogy: *pre-laboratory activities* to allow the learners to prepare well, *teachers' scaffolding* during and after the laboratory activities, and *reflective group discussions* with peers to enhance learning (during and after the laboratory activities). The framework for operationalizing these aspects is presented in the "Workshop and experiments" section below.

When selecting experiments, the following features were emphasized: In order to foster meaningful learning experiences among teachers and students, we looked for so-called *context-based* laboratory activities in which the chemistry was applied to a "real-world situation" [25, p. 53]. For example, the experiments included topics from everyday life such as hard water analysis and polymer properties in diapers. Also, engineering design was demonstrated through the construction of a Lego colorimeter [26]. To make our SLI more feasible in Ethiopian schools, we were interested in experiments that made use of *low-cost and homemade materials and equipment*. Among the low-cost materials we included is a small-scale chemistry equipment, which reduces waste and the use of costly consumables and is made from plastic rather than breakable glassware [27]. Furthermore, the materials used are from the students' everyday life and are free of so-called black boxing (i.e., instruments whose content and principles are sealed and hidden from the learner) [28] to make the principles behind possible to grasp.

Research Questions

To understand to which extent and how the Ethiopian teachers found the SLI pedagogy and the selected experiments to be useful in their classrooms and what experiences they had from using the method during the workshop, we asked the following research questions (RQ):

1. Which features of the SLI did the teachers find readily applicable for their own adaptation of the method in their classrooms?
2. What challenges did the participating teachers foresee in implementing SLI in their classrooms? We also looked at the kind of support they needed to implement the SLI method in their classrooms.

RESEARCH CONTEXT AND METHODOLOGY

This study targeted Ethiopian in-service chemistry teachers who taught in grade 12 classrooms. In the national high school education structure, grade 12 constitutes the last year of the second cycle of senior high school education, at the end of which the students sit the National Higher Education Entrance Certificate Examination. Grade 12 science education is reckoned to be pivotal in implementing the 70:30 policy mentioned above.

Before starting the current study, an informal discussion with school rectors, teachers, and students in the region where the study would be conducted revealed a shortage of laboratory space and facilities in the part of Ethiopia where this study took place. Since large numbers of students (roughly 25% of all students in Ethiopia, see [29], are enrolled in this region), teachers expressed the need to have qualified technical assistants to assist them in their laboratory courses.

Other challenges mentioned in the informal discussions included the expectation of teaching an overloaded curriculum prepared by the government, the decline in students' and teachers' interest in science, and the teachers' lack of knowledge, skills, and confidence to engage in practical experiments—as noted above [4, 9]. The teachers reported that they either demonstrated chemistry experiments before a crowd of over 70 students or simply offered theoretical lectures.

Workshop and experiments

The SLI workshop for teachers was conducted in November 2019 and lasted for two days, about 14 hours in total, so that teachers could be able to participate on the weekend, to avoid collision with their own classroom teaching. Five potentially low-cost (i.e., paper-based galvanic cell, electrolysis apparatus, homemade Lego colorimeter, and disposable diapers) and context-based experiments (i.e., water quality in the hard water experiment and soil nutrients' leaching analysis in the disposable diapers experiment) available from the library of chemical experiments published in the *Journal of Chemical Education* [27, 30-33] were selected, adopted to SLI pedagogy and grade 12 Ethiopian curriculum, and laboratory manuals developed. The SLI-based laboratory manuals were offered to the participants one week before starting the workshop. The grade 12 chemistry topics utilized in the SLI workshop were solutions, acid-base equilibria, electrochemistry, and polymers. At the beginning of the workshop, an hour lecture was offered to the participants on how SLI could be used to support students' learning while doing science. The role of pre-laboratory activities, teachers' scaffolding, and reflective group discussions in enhancing practical laboratory teaching-learning processes in the SLI pedagogy were elaborated on and exemplified and the selected experiments' relevance to the high-school chemistry curriculum was discussed.

The methodological approach employed a PD framework with three phases, as described by [34], and used in laboratory instruction by [35]: forethought phase, performance phase, and self-reflection phase. In *the forethought phase,* the participants actively engaged in pre-laboratory activities (i.e., pre-laboratory quizzes and discussion), in which the researchers provided support by asking, for example, “What is the function of radiation in photometer?” to help students understand the principles of the colorimeter, in the experiment where a small-scale Lego colorimeter was used with a light-emitting diode [32]. The pre-laboratory activities were meant to ensure that the teachers were prepared for the laboratory learning and to help them develop conceptual knowledge, as well as cultivate the interests, motivation, and intellectual confidence necessary for their laboratory experiences [23].

In *the performance phase*, once teachers obtained a brief orientation about the safety issues and the basics of the experiments and laboratory activities, they conducted the experiments in small groups (three to five participants in each group), while the teacher-researcher guided and facilitated the laboratory teaching-learning process by asking questions to help them complete the tasks. For example, teachers were assigned to find out how the unknown concentration of copper sulphate ($CuSO_4$) was determined in the Lego colorimeter experiment using hands-on lab activities (e.g., manipulating the Lego colorimeter, preparing solutions), and minds-on activities (e.g., calculating absorbance and concentration, reflecting on how to use the Beer-Lambert’s law, drawing a calibration curve). In the hardness of water experiment scaffolding activities included asking teachers “Why should the complexometric titration be adjusted at a pH of 6-8?” to guide the teachers’ inquiry process.

In the *third phase, self-reflection*, the teacher-researcher led discussion forums to allow the teachers to reflect on their laboratory experiences; this was an avenue toward greater collaboration and a professional learning community. For example, the teacher-researcher initiated group discussions by posing the question "How could you identify the origin of coffee samples in Ethiopia?" to help teachers recollect what they had undertaken in the colorimeter experiment.

Each of the experiments took approximately two and a half hours, out of which about 20 minutes were allocated to pre-laboratory activities; about 90 minutes were dedicated to the experiment itself and 40 minutes for the post-review discussion forums.

Data and informants

Sixteen high school chemistry teachers (two females and fourteen males) from six different schools in Ethiopia participated in the workshop. Purposive sampling was employed to select participants: Teachers who were found to be hardworking (by their school rectors), who had previously taken part in any laboratory-based training, and whose residence was within 50 miles radius from the first author's base was invited to participate. Seven of the teachers who participated held master's degrees in chemistry and taught grade 11–12 students, while nine of the teachers held bachelor's degrees and normally taught students in grades 9–10, sometimes in grades 11–12. All had followed a pre-service teacher education program with chemistry as their major subject and physics and mathematics as minors. Twelve of the informants had also followed a one-year post graduate diploma in teaching (PGDT) program. Furthermore, all participants regularly attended government-endorsed in-service school-based PD courses on subject-specific teaching methods and "recipe-style" [36] laboratory practices. The teachers had between 9 and 36 years of high school chemistry teaching experience.

Twelve of the sixteen teachers involved in the study were selected for semi-structured focus group interviews. Generally, group interviews were favored over individual interviews because they can be considered more natural settings in which participants can express their viewpoints while discussing them with peers, and therefore the interviews can provide data that might not be accessible otherwise [37]. Also, group interviews are cost-efficient compared to individual interviews. More specifically, focus group interviews were chosen to obtain an in-depth understanding of the experiences of a purposely selected group of the workshop participants. In this case, to avoid statements about the potential of laboratory work in general we were particularly interested in the opinions and experiences of teachers who were experienced in doing chemical experiments prior to the SLI workshop, and who also had demonstrated that they did not mind speaking openly in groups. To make conversation easy and comfortable, the twelve selected teachers were grouped with participants they knew well. Each focus group (FG1, FG2, FG3) consisted of three to five participants.

The focus group interviews were conducted by the first author in the laboratory room of one high school within two days after completing the workshop. Semi-structured interview guide and probing follow up questions were used to elicit sufficient information. The first author moderated the focus-group discussions, balancing between firm steering and keeping the discussion open, in an open-minded and non-judgmental way to avoid researcher's bias. The four planned interview questions that were specifically aimed at gathering data relevant to the research questions for this study were 1) Which aspects of the training did you find helpful and readily applicable in your school context? 2) What support do your students need to learn chemistry through SLI? 3) Did you face any challenges, or can you think of any potential challenges in implementing SLI in the classroom? and 4) What materials (resources) do you need to practice SLI to increase the interest of high school students? We also asked what the participants learnt from the SLI method, and whether or not they thought the method would be motivating for their students.

Each interview lasted between 60 and 100 minutes. The interview data were audio-recorded and stored confidentially. They were first transcribed verbatim in Amharic and then translated into English, as well as checked by an Amharic-English bilingual colleague, who also acted as an external reviewer who checked the questions for researcher's bias. That the participants were able to use their native language in the workshop and interviews instead of English, which is commonly used in teaching, might have reduced the language barriers that could make informants uncomfortable and prevent researchers from capturing participants' views. All participants who agreed to take part in the study signed an informed consent letter. The data collection was approved by the Norwegian Center for Research Data (NSD).

Data analysis

This study employed a qualitative research design that used a multi-phase thematic analysis [38] which included the following phases: 1) Familiarizing with the data through repeated reading of interview transcripts, 2) thorough (inductive) coding working bottom-up from the data while paying attention to features of potential relevance to the RQs, 3) grouping of codes as a first step toward the development of themes, 4) critical examination of candidate themes, and further development and refining of themes and sub-themes in a recursive process going back and forth between codes and themes until valid and coherent themes addressing the RQs had been developed. Included in this process was the analytic and iterative process of writing the theme descriptions, which involved the selection of extracts, editing, further analysis, and re-organization of the data. Finally, 5) both authors were involved in the coding and theme and sub-theme development through regular video conferences and face-to-face meetings. This systematic approach was critical to establishing the reliability of the codes and themes, while phase 4-5 was especially important for the validity of the study. Overall, the steps taken to increase the trustworthiness of the study include thick descriptions (transparency), checking of interview questions with respect to researchers' bias as well as to linguistic precision by an external reviewer, purposive sampling, moderate facilitation, data saturation, systematic procedures for coding and theme-development involving negotiation between the authors, and continuous discussions on interpretations of the data. Three final themes were developed, which captured three essential aspects of SLI as the informants expressed it: (1) SLI is an attractive teaching method; (2) SLI is challenging to implement in the classroom; and (3) teachers need support to teach SLI. For clarity and reading ability purposes, the selected codes that sort under each theme are italicized under each description in the Results section.

RESULTS

Theme 1: SLI is an attractive teaching method

Teachers found the SLI laboratory workshop to be interesting and useful for their own teaching. One aspect of SLI that teachers strongly appreciated was the use of *pre-laboratory activities* that would make them well prepared to conduct laboratory work and include it in their own teaching. For example, John (FG2) said the following:

> The pre-laboratory quizzes are useful for asking myself critical questions like "What am I going to do now? What should I get now? What prior knowledge should I come up with? What knowledge and skills should I be expected to add along the way?" It serves as a means to construct new knowledge, not just as the end of the story, so to speak.

Similarly, Michael (FG3) expressed that he "recognized [that] the pre-laboratory questions are helpful in stimulating students' thinking at the early stage of the experiment." These statements exemplify the views among teachers that the pre-laboratory questions allowed them to think about what they were going to do in the lab and helped them capture the essence of the laboratory activities beforehand. However, some of the participants found it difficult to conduct pre-laboratory activities if they did not have enough background knowledge on the topic in question. As Amen's (FG3) expressed, for example, the lack of prior knowledge "is an obstacle that couldn't make me complacent with the workshop." However, challenging could also mean helpful, as Kibru (FG1) said: "Pre-lab questions were challenging for me. But the questions necessitate our critical thinking and actually I like this challenge—for it offer me an opportunity to scrutinize concepts as deeply as possible."

The participants also appreciated that they were offered support (*scaffolding*). Teachers were of the opinion that students would be able to learn science better if they were given scaffolding that could help them to accomplish difficult laboratory tasks, just as the teachers had been given during the workshop. For example, Lidya (FG1) stated: "…after [participating in] SLI, with the help of researchers' scaffolding, I came to know that polymers…contains an aggregate of monomer units joined in a strong covalent bonding." This example indicates potential for learning chemistry concepts through scaffolded, or supervised, instruction. John (FG2) further demonstrated what such support would mean using an Amharic proverb: "*Kebero siyayut yamir siyizut yadenagir*" ("A drum looks beautiful only when we see it, but it requires a skill to actually play it oneself"), meaning that scaffolding students' learning in the laboratory is a difficult task which requires certain skills, different from the skills needed to offer lectures and "recipe-like" laboratory activities.

The participants also appreciated the *reflective group discussions*. Kibru (FG1), for example, believed "[group discussions] fine-tune the difficulties in grasping chemistry concepts" and John (FG2) said, "It [group discussion] enlightens and help you recall what you have done in the experiment: 'What did I know?' What knowledge did I share with colleagues? What knowledge should others get from me?'" This indicates that the group discussions provided the teachers with opportunities to reflect and evaluate their own and others' ideas and laboratory experiences, which might help to develop their cognitive and metacognitive thinking skills (and their students').

Teachers also thought that the selected experiments were well suited to connect chemical knowledge with day-to-day life experiences (*context-based teaching approach*). For example, John (FG2) said: "When you contextualize the lesson with what you get in your surroundings, you will become more motivated to discover more…." An explicit connection, the teachers reasoned, might help students develop scientific literacy. Amen (FG3) stated: "I think this method [SLI] is very useful to teach students meaningfully by relating what they have learned in the lecture with real concrete experiences. No doubt this will promote their chemical literacy." To the teachers, contextualizing chemical concepts with what students might encounter daily was important to develop their skills to navigate the socio-scientific issues in general and the lesson of interest in particular.

The participants also appreciated the use of simple, *low-cost, and homemade materials and equipment*, which made it easy to teach laboratory courses in a risk-free learning environment. For example, Murad (FG3) noted: “The important features of the workshop for which I was very interested are: It uses easily available materials; it is safe; and free of any hazards.”

In summary, the teachers found SLI to be a cost-effective and pedagogically feasible method for providing meaningful laboratory experiences. In particular, the pre-laboratory activities and reflective group discussions offered participants with opportunities to actively engage in practical laboratory teaching and learning. However, the teachers found that the level of complexity of the laboratory activities should be designed carefully, and sufficient scaffolding be provided to encourage learners to do science on their own. Furthermore, the participants found features such as context-based learning activities and the use of low-cost and homemade materials in the selected experiments to be helpful for the implementation of laboratory instruction in their own classrooms.

Theme 2: SLI is challenging to implement in the classroom

While SLI seems to have contributed to teachers’ interest in science laboratory teaching and learning and to have helped the teachers develop their laboratory experiences, the Ethiopian teachers in our study felt *limited by constraints,* such as ambitious curriculum, shortage of curriculum materials, time, and class size. For example, John (FG2) elegantly expressed this point when asked what possible challenges would prevent him from implementing SLI for teaching practical chemistry courses in high schools:

> Our education system is like people who build houses for rent but are more obsessed with the money than with worrying about the service they have to give to the tenants, so to speak… What prevents us from doing SLI in our classroom are the time constraint and the large class sizes that are not manageable. The fact that the textbooks are too voluminous to finish at the right time also makes it [SLI] unthinkable.

Evidently, John (FG2) holds the view that the Ethiopian government has paid much attention to access to education but less to the quality of education. This viewpoint aligns well with the Ministry of Education report [9], which states that less focus has been given to students' learning outcomes as compared to building schools and establishing lab facilities. Similarly, Taha (FG1) said that "high school chemistry textbooks contain a large amount of information that the teacher is expected to teach," which requires a lot of time.

Teachers also stated that a *lack of sufficient experimental training and experience* hindered them in implementing SLI in their own classrooms. For example, John (FG2) explained that:

"[previously], I did not get sufficient practical laboratory experience, as the possibilities to conduct experiments are very few. [In addition,] … what we have done [before] is not a motivating kind of practical work. Needless to say, I was striving to get to know the names of the equipment, let alone assisting my students in getting relevant laboratory experiences."

Also, little attention had been given to experiments during the teachers' previous training (although some courses had been offered on "recipe-style" experiments). Because of an emphasis on theoretical training, the teachers felt that they lacked the ability to articulate abstract chemistry concepts to their students (i.e., to associate the lesson with appropriate tangible, concrete practical examples and to support students in obtaining meaningful in-depth learning). Tedros (FG3), for example, explained how the lack of training in applying theoretical chemistry to new situations even had consequences for his own understanding of chemistry, as he experienced with the diaper experiment:

> My prior understanding about diapers, for example, was just knowing about their liquid absorbing ability, nothing else. I did not know that diapers contain polymer molecules, nor did I know the idea behind what makes polymers superabsorbent in diapers.

Clearly, Tedros did not know that diapers are comprised of polymers, nor did he know the chemistry of diapers and other related areas where polymers could be applied. Consequently, since he was personally not aware of the connections between polymer chemistry and diapers, he would not have been able to implement such real-life contexts as part of laboratory instruction in his own classroom. As John (FG2) put it, traditional teaching methods "…are far-fetched in addressing the [chemistry] concepts…."

Another challenge that teachers in all groups regarded as an obstacle to implementing SLI in their classrooms is the *lack of lab facilities*. Based on her own teaching experience, Laura (FG1) said the following: "[We] quite often ignore many experiments in our school thinking that the equipment and chemicals are expensive." Other teachers, too, shared Laura's description of the lack of equipment (e.g., a digital balance), which prevented them from conducting experiments in their classrooms. As Lidya (FG1) said, "[Y]ou will realize how embarrassed you feel standing before your students when what you have taught is not integrated with real practical experiences." This was a sentiment echoed by Kibru (FG1): "I am afraid [that I will not be able] to allow my students to do practical experiments." The statements from these three teachers illustrate how hard it might be to conduct experiments regularly due to the lack of laboratory facilities. However, teachers were inspired by the selection of experiments in the workshop and aspired to search for low-cost and homemade materials that could be suitable for their high school chemistry experiments. Laura regarded it as "a mistake to ignore experiments" and was determined to include low-cost materials in her laboratory teaching after the SLI workshop. Kibru was eager to apply what he had learned in the SLI workshop:

> I came to recognize that we should not wait for the school to buy such and such chemicals and equipment; instead, I began searching for locally available materials to replace expensive chemicals with something cheaper.

Furthermore, participants showed that their students' *negative attitudes toward science* might prevent them from implementing SLI to their classrooms. For example, Kibru (FG1) thought that "some of the social problems existing in the country, such as unemployment and political chaos and instability," have reduced his students' motivation for learning science. Murad (FG3) found it problematic that students believe "…that chemistry experiments are complex, time consuming, and need only expensive chemicals and equipment." *Little faith in the use of low-cost experiments* was also a common attitude among teachers in the workshop. For example, Tedros (FG3) said: "We have a mindset that chemistry is something that requires a well-furnished laboratory." Kibru (FG1) also stated that he "had never believed in that the low-cost [and small-scale] titration kit would help to determine the hardness of water." Attitudes of students and teachers alike were therefore perceived as a challenge in implementing SLI in chemistry classrooms.

Despite the many positive aspects of SLI, many teachers found SLI to be challenging to adapt in their own classrooms. Specifically, they were concerned about how constraints, such as curriculum overloads, little time, and lack of lab facilities, could impede adapting SLI in high school laboratories. The teachers also felt that their lack of sufficient experimental training and experience alienated them from science, and that the negative attitudes toward science among students and teachers alike made it difficult to implement SLI in the teachers' own teaching practices.

Theme 3: Teachers need support to teach SLI

Three sub-themes emerged from this main theme. The first sub-theme, "to learn the SLI method," provides insight into the kind of support that teachers said they need from researchers when they were trained on how to apply the SLI method. "To motivate students' science learning," the second sub-theme, describes the support that teachers need to motivate their students to actively take part in SLI instruction, and the third sub-theme, "to make SLI sustainable," arose from several participants' interest in obtaining support that would help them implement the method on a permanent basis in their own classrooms.

To learn the method. Teachers recognized that PD takes time, and some teachers were overwhelmed with their laboratory experiences from the workshop. Particularly, these teachers reiterated that *getting regular laboratory training is imperative* for understanding the SLI method well. For example, Tedros (FG3) said, "Two days are too short to grasp this [SLI] method…had we had enough time to discuss what other options might be possibly used, we could have benefitted more from it…." Michael (FG2) further described that the two-day workshop was not enough time to learn the method: "Had it been given in a relaxed way, I would have extinguished many of my misconceptions."

Similarly, teachers thought that if they had the opportunity for *sharing experiences with university staff through seminars and research projects*, they could enrich their chemical knowledge and experiences with the SLI method. For example, Michael (FG2) reiterated that participating in such discussion forums with university staff might help to "grasp chemical concepts very well" and, as John (FG2) expressed it, "to share experiences … about how to prepare a standard lesson plan." Michael's and John's comments can serve as examples of the views among teachers that researcher-led discussion forums might be useful for developing teachers' content and pedagogical content knowledge. It seems that the scientific discourses they were exposed to as part of the workshop opened teachers' eyes to the possibilities of peer collaboration initiated by researchers—for example, preparing lesson plans jointly and discussing post-laboratory questions, and reflecting upon their laboratory experiences to enhance their conceptual understanding.

To motivate students' science learning. Participating teachers also expressed the need for researchers to *arrange practical tutorials* for the teachers while in training; if the teachers have more hands-on experience, this will help to develop their students' motivation and scientific practices. For example, John (FG2) said: "I guess, teachers could stir up their students' motivation for learning laboratory courses when they obtain sufficient tutorials from researchers." Teachers even felt the need to *get motivational support from researchers both in and out of the classroom* to motivate students' science learning. For example, Amen (FG3) described the need to take his students to university laboratories to increase their desire to learn science in the future:

> [Quite] often they [students] also want to visit laboratories in universities, as this will help them to be more aspired to pursue chemistry with great effort in the future. For instance, it is nice if you [researchers] demonstrate how the centrifuge device works, since they do not find it in their high school laboratory.

This exemplifies the view among participating teachers that the high school students' interactions with the university laboratory learning environment might aspire them to pursue science studies, such as SLI. John (FG2) further explained it as follows:

> We need you [university staff members] to aspire to and motivate our students through these [SLI] experiments. Those who have gained a lot of experience and practical laboratory skills from overseas…should bring locally available and easy-to-make equipment to our schools to impress our students.

Evidently, John held the view that experienced researchers could intrinsically motivate students by conducting low-cost experiments (exactly as what they have done in the workshop) in students' schools, since it might help capture students' interest in learning science.

To make SLI sustainable. Teachers reflected on what they thought were important for making the SLI method sustainable in their own classrooms. Firstly, they thought that *adapted SLI material resources should be made available*. As a first step, Yirga (FG3) expressed a dire need to get the SLI teaching resources available in the teaching laboratories: "It is worth requesting that all the laboratory teaching materials that we have used during SLI [workshop] should be supplied to high schools' laboratories." Further to this, John, for example, said that "SLI design must take into consideration the large content and the scope of high school chemistry textbooks." John's concern was that teachers should not be unnecessarily burdened with activities that require much effort and time to complete (i.e., both the ambitious curriculum and the preparations needed for doing practical experiments in the laboratory classrooms were demanding for the teachers). Thus, John suggested that SLI should cover a reasonable number of experiments that should be available to teachers, which could be done within the allowed time frame. Also, the scope of the SLI lab activities should be in line with the existing curriculum materials.

Another support needs that teacher deemed important for making SLI sustainable in the classroom was the need to get *qualified lab assistants*. For example, Adam (FG2) said, "There should be a way that can reduce teachers' burden as they both offer the lectures and takes the role of a laboratory assistant." In addition, teachers indicated that the adaptation of SLI to their own teaching would be more feasible if *students learned about SLI in lower secondary school* (grades 9–10) instead of first learning about this method in upper secondary schools (grades 11–12). For example, Amen (FG3) said: "SLI training should be offered as a basic level starting from grades nine to ten." This is because, as Laura (FG1) explained, "students can develop their chemical knowledge and increase interest in laboratory practices at the early stage [of their schooling]."

In summary, teachers were in favor of implementing SLI training on a permanent basis through a wedded collaboration with university staff to better learn the laboratory teaching method, and to become inspired. Furthermore, they expressed the need for regular in-service laboratory training. To make SLI sustainable in high school teaching laboratories, the teachers desired to obtain ready-made SLI-adapted resource materials that were in line with the curriculum, qualified lab assistants, and begin SLI at early schooling.

DISCUSSION

RQ1: Which features of SLI did the teachers find readily applicable for their own adaptation of the method in their classroom?

Laboratory-based PD opportunities play a critical role in promoting teachers' abilities in and attitudes towards translating new pedagogical interventions, such as SLI, into their teaching practices [18]. In the present study, too, participants highlighted that the SLI laboratory workshop was useful for adapting the method in their own laboratory teaching. The features the teachers emphasized are italicized below.

Participant teachers found *pre-laboratory quizzes and discussions* beneficial to their understanding of chemical concepts and laboratory processes, as well as a way of stimulating curiosity about the laboratory beforehand, which are in line with findings by e.g., [23, 39]. It appears that the pre-laboratory activities made the teachers in our workshop perform well in the execution of the laboratory activities as it provided them with the leverage to delve into thoughtful engagement in the theoretical and practical aspects of the laboratory. The opportunity to prepare for the laboratory activities seems to have minimized the potential cognitive load that might otherwise have been created in the complex laboratory learning environment, as pointed out by [23]. That teachers obtained information about the laboratory in advance also appears to have increased their motivation and reduced negative feelings about laboratory instruction, in line with what [39] have found. However, some teachers reported about their lack of competence in performing the pre-laboratory tasks and hands-on SLI-lab activities. A similar finding was reported by [40]: The pre-service teachers showed lack of competence in preparing chemical solutions because they had limited understanding of the relevant chemical concepts, and also because they had not acquired the necessary practical laboratory skills.

The participants also described that conscious engagement in scientific "talks" and "actions" (i.e., to think and act upon lab activities, used by [41] *scaffolded by the teacher-researcher* offered them the chance to gain some laboratory learning experiences. This finding aligns with the results reported by [41] on the effect of scaffolding on students' observation skills when doing laboratory activities, which consequently led to increased learning. According to [19], scaffolding should be done to improve science learning by having active teacher–student and peer interactions, as well as by integrating learners' thinking into actions. Similarly, [1] who made meta-analysis suggested that laboratory instruction that provides students with sufficient time and opportunities for prompting questions, reflection, and feedback about their ideas could result in enhanced conceptual understanding and metacognitive skills. This is consistent with what the participants said *reflective group discussions* had done for them: it helped them to gain collaborative group work habits and improved their cognition and metacognition skills.

RQ2: What challenges did the participating teachers foresee in implementing SLI in their classrooms?

The present study has pointed to some constraints that might impede teachers from implementing SLI-type laboratory instruction. Teachers who participated in our workshop felt that *lack of quality curricular materials, little time and overloaded textbooks* in Ethiopia were important hinders for the adaptation of SLI in their classrooms. Also, teachers reported that they had *little confidence in their own ability* to teach and design student-centred laboratory activities in their school context. The participants were experienced teachers, but they reported that they did not have enough background in chemistry content to use their day-to-day life experiences, nor did they possess the experimental skills needed to design chemistry laboratory courses and give laboratory instruction. This may be because participants had been largely exposed to teacher-centered laboratory instructional practices in their teaching as well as during their training. *Lack of theoretical and practical training* might have prevented participants from learning SLI and from implementing the method in their classroom. [1] Asserted the following:

> Many preservice and in-service courses in science and in science teaching and learning provide very limited direct experience, if any, through which the teachers can develop the skills needed to organize and facilitate meaningful, practical learning experiences for students in the school science laboratory (p. 45).

This implies that sufficient theoretical and laboratory training are important factors for teachers when they are implementing new laboratory strategies in their own classrooms.

Another challenge that participants believed significantly hindered the implementation of SLI in their classrooms was the *lack of lab facilities*. As evident in the statements of in-service teachers' shortage of basic lab facilities forced them to revert to traditional teacher-centered instruction in their schools. This observation is at odds with what the [9, p.25] report indicated—namely, that initiatives such as "school improvement packages" have been introduced to facilitate the science teaching-learning process. In our experience, the increasing size of high schools is partly to blame for the lack of facilities; in such circumstances it might be difficult to establish the necessary spaces for learning. Indeed, the lack of lab facilities seems to be a common problem in teaching chemistry in African high schools and elsewhere (e.g., [8, 42-43]). Nonetheless, earmarked laboratory expenses per se cannot guarantee that teachers will be successful in teaching laboratory practices; instead, the instructor-driven "scaffolding and structure of the laboratory activities determine, if any, of the positive learning outcomes associated with laboratory activities occur" [9, 17, p. 136].

Students' negative attitudes to science, which reduces their motivation to learn science, was another challenge that participants perceived would impede them from implementing SLI in their own laboratory classrooms. [44] Recommended that the design of laboratory teaching strategies should consider how such a laboratory program would create a positive learning environment and boost students' attitudes and motivation for learning. This is in keeping with what SLI participants described concerning how hands-on SLI lab activities and the support structure characteristic for the pedagogy had increased their motivation for learning through SLI. Teachers demonstrated such a viewpoint when they indicated that they wanted to replace traditional school experiments with SLI by identifying low-cost materials, equipment, and chemicals for their own teaching, and by instructing students by providing support in the form of pre-laboratory activities, group learning and post-laboratory reflections.

Teachers need support to teach SLI in their own classrooms

Changes in teachers' classroom teaching practices, attitudes, and beliefs, as well as students' learning outcomes, are a long process [12], and thus participants wanted to acquire additional laboratory training from the researchers to develop the necessary competences to teach SLI in their classrooms. The participants highlighted the *need to engage in seminars, SLI-based research projects, and discussion forums*, as well as to *take part in regular laboratory training and tutorials with researchers*. Previous research where pre-service and in-service physics teachers discussed how to plan practical work, suggests that discussing challenges with instructors and peers might help them be better prepared for facing those challenges in their own practice [42]. Similarly, teachers who participated in our workshop indicated that the reflective group discussion would be a good way to develop their laboratory experiences in the preparation of lesson plans, while improving their conceptual understanding through collaborative learning. The fact that the participants did not have previous experience with SLI-type instruction makes this approach demanding.

Teachers suggested that *adapting SLI material resources, acquiring qualified high school lab assistants, and introducing SLI to lower secondary schools* would help implement SLI in upper secondary classrooms. Considering the teachers' own report about lack of chemistry knowledge and practical experience, it would be difficult for them to design and develop hands-on SLI laboratory activities and manuals on their own. Lab assistants can help them prepare solutions and facilitate the experiments. To master SLI at higher levels where the need for chemistry competence is high, teachers could start by practicing the method in the lower grades.

Limitations to the study

Teachers were interviewed only once. A longitudinal study in which teachers are followed over a few years could provide more in-depth insight into their views about SLI and the challenges in implementing it in their classroom. Although the interview data were rich, and data saturation was reached, the absence of metacognition from the participants' teaching culture [45] might have limited their ability to reflect on their views on the SLI workshop. Moreover, since the SLI workshop was perhaps new and unique to the participants, they might have responded in favor of this method because of its "novelty effect" [46]. Nevertheless, the teachers' reflections, as reported in this study, could provide significant information on how high school teachers could implement well-planned laboratory instruction such as SLI in their own school contexts. Thus, this research not only confirms existing studies but also serves as a meaningful basis for advancing research on teachers' scientific practices and designing and implementing teacher PD programs, thereby discouraging the taken-for-granted traditional laboratory teaching strategies in particular and the lecture method in general at different levels of science education.

CONCLUSIONS AND IMPLICATIONS

Our study suggests that SLI has the potential to create a conducive laboratory learning environment and provide teachers with collaborative learning opportunities and skills. Therefore, SLI might be useful in developing teachers' agency—that is, providing them with more opportunities to autonomously make choices, engage in independent action, and take responsibility for students' science learning based on their own teaching practices. The implementation of SLI can help to overcome existing challenges Ethiopian teachers face related to laboratory instruction. This study also suggests how to incorporate at-home, inexpensive, safe, and relevant student-centered, hands-on and minds-on laboratory activities in high school science curriculum to promote students' engagement and learning. The application of pre-laboratory activities, teachers' scaffolding and reflective group discussions in the low-cost and small-scale as well context-based chemistry experiments might well equip teachers with diversified teaching-learning practices, thereby encouraging teachers to design and implement more experimental work in chemistry in Ethiopian high schools and elsewhere.

To ensure effective implementation, we recommend that Ethiopian high school teachers and stakeholders such as school rectors, science educators, and policymakers, meet to discuss how to facilitate the use of student-centered, well-planned laboratory instruction, establish basic laboratory facilities at rural as well as urban schools, and offer a PD program on such laboratory instruction for pre-service and in-service teachers on a regular basis. Finally, to better understand the in-service teachers' views on SLI, longitudinal PD programs—along with investigating the effect of SLI on students' science laboratory learning—should be provided at different levels of science education.

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TEACHERS' PERCEPTIONS ON THE IMPACT OF CONTINUOUS PROFESSIONAL DEVELOPMENT TO PROMOTE QUALITY TEACHING AND LEARNING OF CHEMISTRY: A CASE OF RWAMAGANA SECONDARY SCHOOLS, RWANDA

Jean Baptiste Bunane*, Edwige Kampire and Claude Karegeya
African Centre of Excellence for Innovative Teaching and Learning Mathematics and Science (ACEITLMS), University of Rwanda- College of Education, Rukara Campus, Rwanda
Corresponding Email: bonajeanbaptiste73@gmail.com/ bonajeanbaptiste@yahoo.com

ABSTRACT

The study was designed for the purpose of investigating the chemistry teachers' perceptions on the impact of Continuous Professional Development (CPD) in promoting quality teaching and learning of chemistry. The qualitative approach and multi-methods sequential research designs were used in this study. Closed-ended questionnaires, semi-structured interviews and focus group discussions were used to collect data. The collected data were thematically analyzed. Twenty-four participants including 5 head teachers, 4 deputy head teachers in charge of studies and 15 chemistry teachers were involved in this study. Data from both questionnaires and interviews were transcribed verbatim and analyzed thematically. The findings showed that chemistry teachers recognize the impact of CPD programs as it enhances their pedagogical and content knowledge development, to improve the quality of teaching and learning of chemistry. However, the results revealed that CPD activities do not promote students' learning directly. Additionally, the study proved that chemistry teachers have positive perceptions towards the impact of CPD programs. The study recommended that a well-structured systematic policy related to teacher's continuous professional development must be developed at national level. Further research to explore the impact of CPD activities on promoting the student learning in Rwanda should be undertaken. *[African Journal of Chemical Education—AJCE 12(2), July 2022]*

INTRODUCTION

For any nation to attain the quality education , it requires many factors such as qualified teachers that are well equipped with the necessary pedagogical content knowledge (PCK) and skilled school leaders with a need school leadership [7]. However being qualified does not mean that you are well equipped with knowledge, skills , attitudes and values to provide the quality education [11]. This is explained by fact that education is dynamic, and teachers have to be regularly updated with the new approaches that are trending in recent era [9].

Over the past years, a new consensus has emerged that the teacher quality is one of the most significant factors for students' achievement and educational improvement [16]. Teachers need to be empowered to further develop expertise in subject matter content, technologies, and other essential elements that lead to high standards or quality teaching [1]. In Rwandan education, teachers were underpinned to be updated by the introduction of the competence-based curriculum (CBC) in 2015 through which learners need to acquire necessary competences to be successful in the 21^{st}century. Teachers were encouraged to implement the CBC despite some constraints for improving the quality of Education [10]. To support the effective implementation of CBC, teachers were equipped with skills and knowledge as a solution to implement efficiently the CBC. The implementation of CBC demanded that teachers had to pass through different models of continuous professional development (CPD) [2].

Teachers are the first to undertake an important task to bring the change to any education system [5]. According to [11], the quality of education cannot go beyond the quality of the in-service teachers and school leaders since students' learning is the harvest of what goes on in the classroom. According to [15], teachers and their continuous professional development (CPD) are crucial in determining the success of any educational reform directly and the future of the society indirectly. Professional development in general involves the career-long processes and related system and policies designed to enable educators (teachers, administrators, and supervisors) to acquire, broaden, and deepen their knowledge, skill, and commitment in order to effectively perform their work roles [13]. The stages of professional development for teachers in general consist of pre-service training, induction program and in-service training known as continuous professional development [4].

Teacher training is fitted with career to develop understanding and basic skill in learning process. Teachers have to be professional in teaching and grow in their career continuously [1]. The recent research done here in Rwanda related to CPD of teachers were focused on the importance of CPD program for teachers but there is no empirical evidence which show the effect of CPD on students' learning [14].

The following research questions guided this study for a better understanding the impact of continuous professional development on the quality of teaching and learning chemistry.

1. What are the perceptions of chemistry teachers on the role of CPD in teaching and learning chemistry?
2. How can the CPD impact on the improvement of student's performance in chemistry?

METHODOLOGY

In this study, multi-methods sequential design and qualitative data were used to collect data from completing questionnaires, focus group discussions and semi structured interviews.

The target population of the study was composed of 15 chemistry teachers, 4 deputy head teachers in charge of studied and 5 head teachers from secondary schools found in Rwamagana District. However, the sample population of the study was purposively selected from the five selected secondary schools and a total of 24 participants were involved within which 15 are chemistry teachers, 4 deputy head teachers and 5 head teachers. The participants were chosen in such way that chemistry teachers had completed continuous professional development course in coaching and mentoring while the head teachers and deputy head teachers in charge of studies completed Continuous Professional Development Diploma course in Effective School Leadership (CPD-DESL) in 2019 delivered by University of Rwanda-College of Education (UR-CE) in partnership with Rwanda Education Board and VVOB Education for development [17].

Questionnaires and focus group discussions are separated but ‘connected’ [18]. The focus group discussion was done with all the chemistry teachers at focus school. Semi-structured interviews were done by chemistry teachers, head teachers and deputy head teachers in charge of studies guided by the researcher. The interview guide was made up of open-ended questions to permit the researcher to gather accurate information. The questionnaires used were different for chemistry teachers and schools’ leaders and were made off two parts, one part for correction of participant educational background and part two for correction of views up on continuous professional development programs. However, some questions were cross-cutting for ahead teachers, deputy head teachers in charge of studies and chemistry teachers.

To confirm the validity of the study, the research instruments were checked by three experts (3 evaluators) from University of Rwanda-College of education prior to the starting of the study in view of the study’s objective. Reliability was proved by incorporating the audit trail. Before drawing conclusions from the findings, the recordings, filled questionnaires and transcripts from interviews audios were sent to 3 experts to ensure that only decisions were taken from participants ‘responses and not affected by investigator intentions.

The participant identification was anonymous and confidential kept before to proceed data collection. Permission from district office was got, consent form has been given to each participant to agree to participate voluntary. To optimize the trustworthy of the study transcriptions from interviews, the transcripts were sent back to the interviewees to make sure that there is no added information to their views. Data were analyzed through qualitative methods whereby thematic approach were employed to finds results related to the research question. This method was used in this research because the researcher wanted to investigate the peoples ‘perception on the impact of Continuous Professional Development in promoting quality teaching and learning of chemistry.

RESULTS AND DISCUSSION

Perceptions of chemistry teachers on the role of CPD activities in teaching and learning

When analyzing the findings from all sources either from transcripts of interviews or from the ticked or selected answers in questionnaires. Findings from chemistry teachers in all the selected schools were analyzed to discover their perceptions towards the impact of participating in different planned CPD activities at their schools. Peer tutoring (peer teaching), lesson study and Community of practice were identified by all chemistry teachers as the most CPD activities frequently performed and beneficial at school. The findings from focus group discussions and semi-structured interviews again showed that when teachers share experiences and views about any concept and giving feedback through collaborative learning, results to improvement of teacher’s practices and knowledge retention. This is in agreement with the findings of the study of [6] where they found that college of teachers’ education graduate and saying that are finished products, rather they need professional development through collaboration with senior teachers for exchange of experiences.

All of the 5 head teachers and 4 deputy head teachers in charge of studies confirmed from the questionnaires that Community of Practice, lesson study and peer teaching are the most CPD strategies that are effective and teachers benefit more from them to improve their teaching practice. On other hand, the attendance in workshop, trainings, involvement in action research, case study discussion and field visit were highlighted from questionnaires as the least beneficial strategies of CPD and are identified as passive CPD activities.

The figure 1 below indicates chemistry teachers' perceptions on the benefits (role) of CPD activities during their teaching practices.

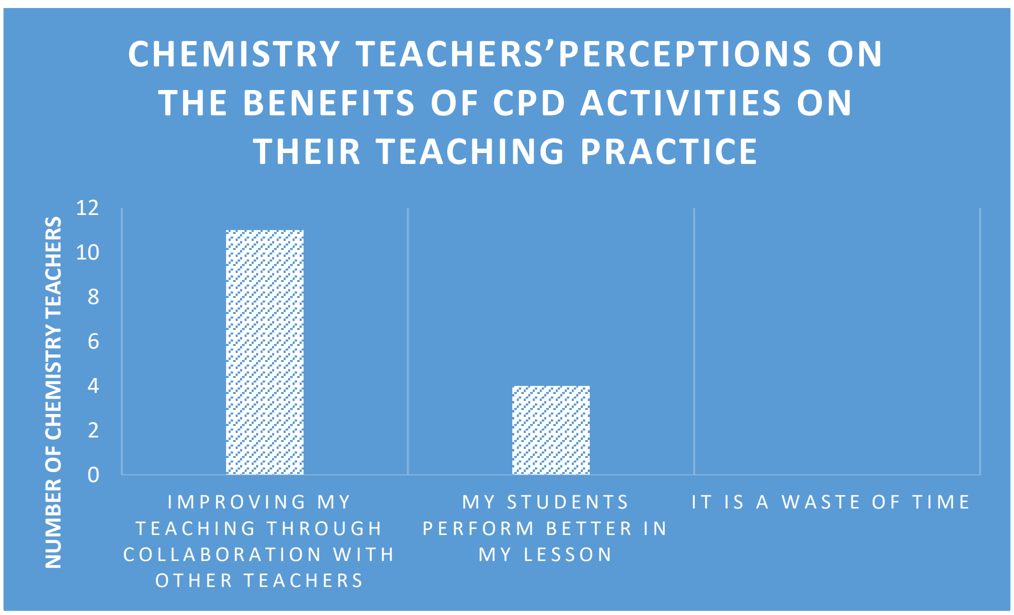

Figure 1. Chemistry teachers' perceptions on the benefits of CPD activities.

With the results presented in figure 1 above, it shows how chemistry teachers perceive the benefit of CPD activities for both improving teaching practices and affecting students ‘performance. 11 out of 15 teachers emphasized that CPD programs help them to improve their teaching practice while only 4 out 15 agreed that CPD programs affect students ‘performance.

The following figure 2 indicates the views of Head teachers and Deputy head teachers in charge of studies on how CPD activities improve teacher's teaching practice.

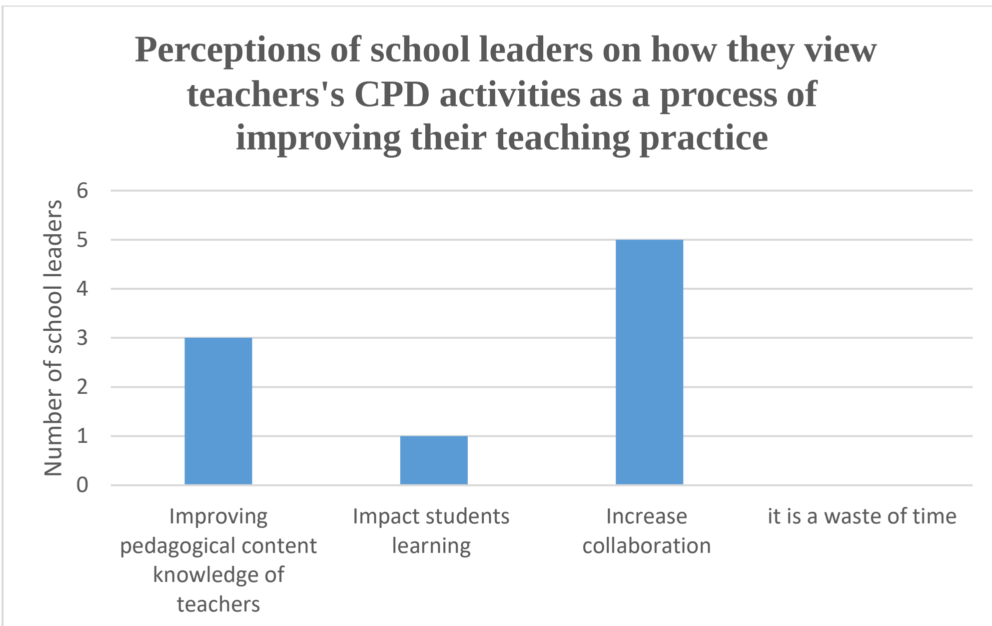

Figure 2. The perceptions of school leaders on teachers' CPD activities

From the figure 2 above, the results showed that 5 school leaders perceive that CPD activities increase collaboration of teachers, 3 school leaders agreed that CPD activities improve pedagogical and content knowledge while only 1 school leader agrees that CPD activities can impact students' performance. This is in agreement with the study conducted by [13]. He said that to improve teaching in the classroom, professional development activities must be collaborative, long term, and content driven.

The following figure 3 shows the findings from questionnaires completed by chemistry teachers, head teachers and deputy head teachers in charge of studies on types of CPD activities that carried out by teachers at school and their frequencies.

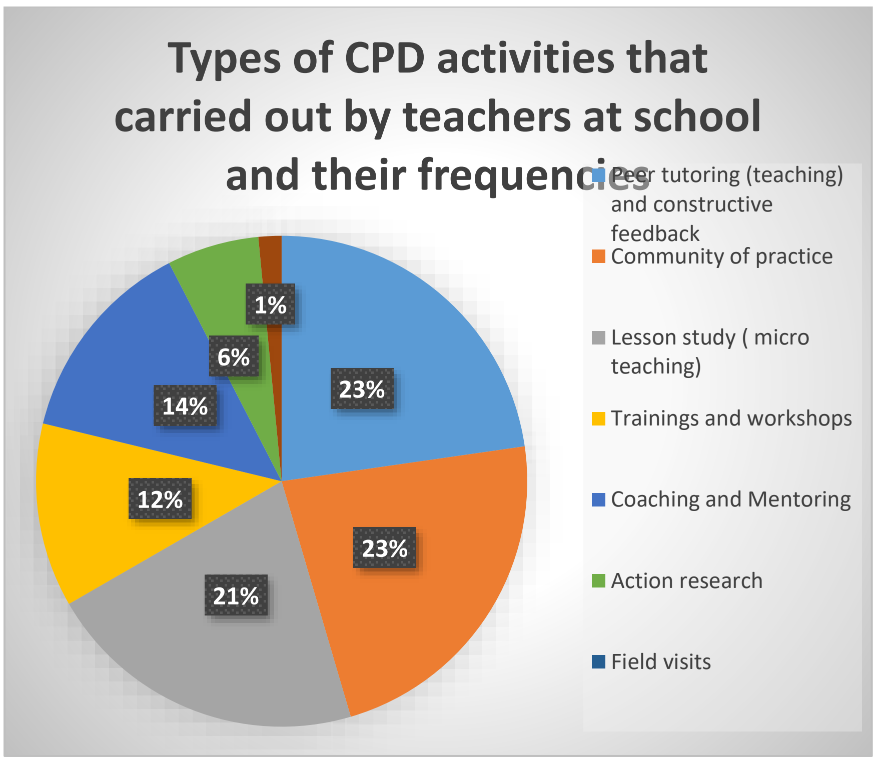

Figure 3. Different types of CPD activities that teachers carried out at school level

From the figure 3 above, the findings show that peer teaching (tutoring), constructive feedback, community of practice and lesson study were reported as the most practical activities done in all the schools. Both peer teaching and community of practice represented each 23%, microteaching represented 21% followed by coaching and mentoring (14%), training and workshops (12%). Action research and case study discussion represented less than 10% while field visits represented 0%. These findings are in agreement with those of [12] who found that peer teaching, community of practice and microteaching are the main activities that are beneficial for teachers because they make teachers to be actively involved in their teaching. Workshops, trainings, coaching and mentoring, case study are not commonly done at all Schools.

Finally, from the results, researcher confirmed that both chemistry teachers and school leaders have positive perceptions towards the impact of CPD activities in broadening pedagogical content knowledge. However, the results showed again there is no evidence to demonstrate the direct impact of CPD activities on students learning. This is supported by some authors in their literatures such as [6], [2]. All confirm that through CPD programs, teachers enhance their PCK and contribute a lot to their teaching practice but CPD effect to students' learning is not demonstrated empirically.

Challenges that hinder teachers' participation in CPD activities

All the participants interviewed highlighted some of the challenges or difficulties faced in relation to their professional development experiences. The figure 4 below shows the challenges by teachers during CPD activities.

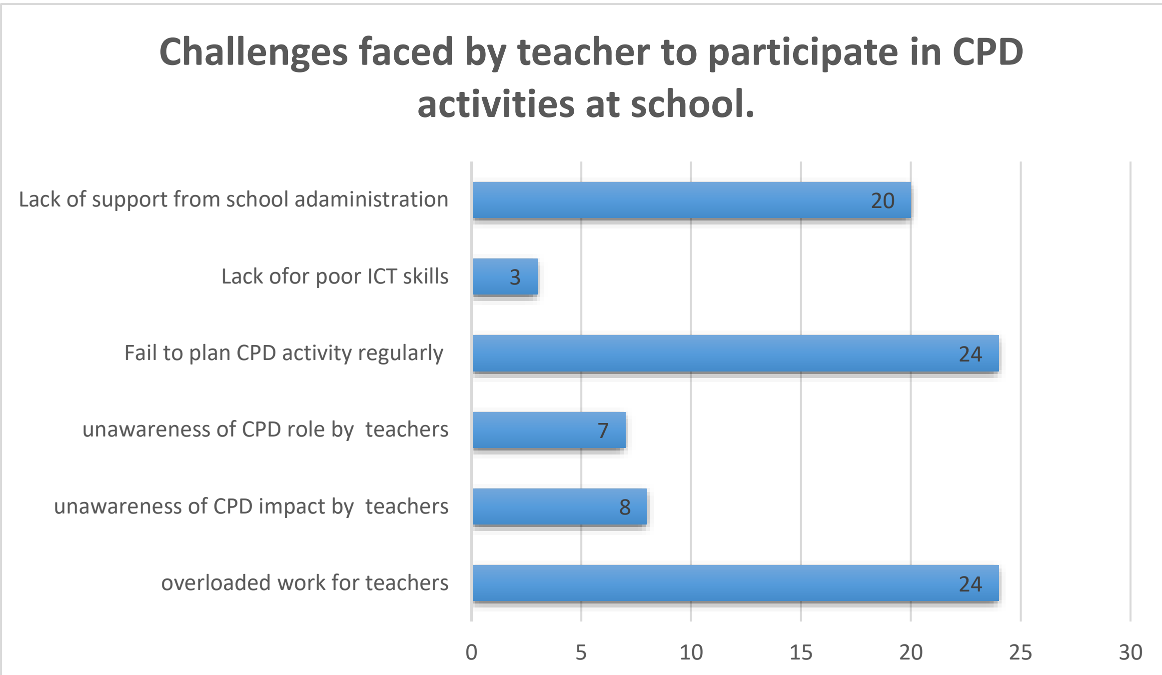

Figure 4. Challenges faced by teachers to participate in CPD activities

The figure above showed that the most challenges faced in the implementation of the CPD programs at school level include lack of sufficient time (overloaded work for teachers), fail to plan

CPD activity regularly (poor planning), lack of CPD framework, and lack of support from School Leaders (Figure 4).

The findings from the above Figure showed that all the mentioned challenges can hinder teachers to participate in different CPD activities. However, they don't affect CPD programs at the same pace. For example, all the 24 participants through completing questionnaires, mentioned that lack of CPD framework (fail to plan CPD activity regularly) and overloaded work for teachers (lack of sufficient time) as the most challenges that hinder the effectiveness of CPD programs.

The participants highlighted some of the barriers identified as limiting the opportunities available for teachers to engage in more school-based professional development. The biggest barrier identified is time. Chemistry teacher from one targeted school said:

> *For us, the most concerns we encounter, I can mention overloaded timetable and lack of opportunities to be engaged in such activities; to get time for those activities is not easy". "The challenge we face here is daily workload and insufficient time. Sometimes, the CPD activity is organized after the class is ending when all the teachers are tired.*

Chemistry teachers emphasized that they had problem to find a suitable time to formally meet and discuss issues related to their practice with their colleagues. Lack of well-planned CPD activities, insufficient support from the school administration, Overloaded timetable for teachers were mentioned from both 24 interviews and 24 questionnaires like barriers for teachers to participate in CPD activities. However, they do not hinder teachers at the same rate. This was emphasized by [3], [14], they showed in their findings that lack of teachers' motivation, lack of CPD plan, minimal support and monitoring from school should affect teachers to be involved in CPD activities.

The impact of CPD on the improvement of student's performance in chemistry

When analyzing data from interviews and questionnaires about the impact of CPD activities on students' performance, both school Leaders and Chemistry teachers emphasized that CPD activities can improve teachers' pedagogical content knowledge through collaboration especially when CPD activities are well organized and performed especially when community of practice is empowered. However, the discrepancy between teachers' perceptions towards the impact of CPD activities to the students' learning and school leaders was mentioned. 13 of 15 chemistry teachers said that CPD activities can indirectly impact students 'performance, on other hand, results from School Leaders showed that there is no clear evidence indicating that CPD activities impact on students' learning directly. This is due to the fact that students' performance is influenced by many other factors rather than CPD activities. This agreed with findings of [2] and [12] who found that CPD activities help teachers to improve PCK but there is no evidence showing their direct impact on students' performance.

CONCLUSIONS AND RECOMMENDATIONS

This study aimed at investigating teachers' perceptions on the impact of continuous professional development to promote quality teaching and learning of chemistry. The findings from the study showed that both chemistry teachers and school leaders have a positive perception towards the impact of CPD activities on broadening teachers' pedagogical content knowledge. However overloaded timetable, shortage of time, lack of support for teachers from school administration and lack of CPD framework were found as the challenges to effective implementation of the CPD programs at school level. Collaborative learning, lesson study, and peer teaching (tutoring) were identified as CPD activities to improve teachers' PCK and teaching practices.

This study was limited only to small geographical scale of Rwanda. Thus, the findings should not be generalized to the country level. The data collected also was limited to only chemistry teachers and school leaders who attend CPD course. Thus, the results may not be generalized to all chemistry teachers and school leaders.

Based on results of the study and the limitation mentioned, the present study recommends that (i) School leaders have to provide the necessary support for teachers and create a good collaborative school climate whereby the teachers' needs are pinpointed. (ii) The government should assess the policy governing teachers' CPD programs. (iii) The government should adjust the financial structural resources in different educational aspects so that the emphasis should be put on teacher's CPD activities which help teachers to promote quality of teaching and learning. (iv)A well-structured systematic CPD policy which explain clearly the CPD framework at school level has to be developed and inserted into teacher's weekly timetable. (v) Lastly, further studies to examine the impact of CPD activities on students 'performance have to be done.

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CONFLICT OF INTEREST

Author declares no conflict of interest

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INDIGENOUS KNOWLEDGE TRANSFER: THE CASE OF TRADITIONAL MEDICINE AND AGRICULTURAL PRACTICES

Teshager Ali[1], Solomon Belay[2] and Sutuma Edessa[2]
[1] PhD candidate, Department of Science and Mathematics Education, Addis Ababa University, Ethiopia.
[2]Department of Science and Mathematics Education, Addis Ababa University, Ethiopia.
Corresponding author email: Teshagerali123@gmail.com

ABSTRACT

Indigenous knowledge is a natural resource and heritage which need to be documented and transferred from one generation to another. It is embedded with the everyday life of people who produced it so that it is a way of their living and being. It is also a social capital and social asset to solve local problems. It consists of both tacit (implicit) and explicit knowledge. The paper defines indigenous knowledge as a system of knowledge that emanated from the socio-cultural milieu of people and knowledge transfer. The transfer of knowledge and skill from experts to other members of the community is believed to be used. However, knowledge is not transferred as it stands, instead, new knowledge is added to the previous one in each step of transfer, that entails indigenous knowledge is not fixed but dynamic. The purpose of this paper is to explain how indigenous knowledge transfer occurs based on empirical data. The study employed qualitative case study. Data were gathered using semi-structured interviews, informal discussions, and field notes. The voices of respondents were video recorded that were later transcribed verbatim. Thematic analysis was used for the study. This includes both conceptual and relational thematic analysis to make codes and categories. As a result, categories such as apprenticeship learning and learning by doing were developed. Out of these categories a theme of experiential learning emerged. This indicated the conclusion that indigenous knowledge transfer can contribute to the pedagogy of science education if it is integrated and applied in schools. *[African Journal of Chemical Education—AJCE 12(2), July 2022]*

INTRODUCTION

Since the term indigenous knowledge is value laden, it possesses to have different meanings, as a result there is no standard definition of Indigenous Knowledge (IK). However, [1] opines that IK is regarded as Indigenous Science (IS), Folk Knowledge (FK), Traditional Knowledge (TK), Traditional Ecological Knowledge (TEK), Local Knowledge (LK), and People's Knowledge (PK) among others. We can use these terms without considering their hegemonic stances. This is because Westerners tried to define IK by undermining the knowledge and the people who produced it. Accordingly, Westerners define IK as primitive, local, traditional, non-scientific, irrational, and static as if IK is frozen in time and place [2].

Generally, indigenous knowledge (IK) is defined as a form of knowledge and skills that societies develop outside the mainstream scientific knowledge or as a foundation for the scientific knowledge. But this study is guided by Ogawa's definition of IK that refers to it as 'systems of knowledge of nature developed by a culture indigenous to a region or country' [3]. With this understanding, traditional Ethiopian knowledge of nature is IK. Similarly, the mainstream Western scientific knowledge about nature is by itself IK of its scope. Indigenous knowledge is a kind of knowledge and cosmology not only related to the past but also the present [3]. This means, IK is not static and not confined to only original inhabitants as it is widely assumed to be, rather it is dynamic which can be created, modified by any one at any time. Any community can produce IK, rural or urban, original or immigrant based on empirical data or rational ways of knowing [4]. However, [5] posits the empirical and rational form of knowledge is culture-laden that differs based on a worldview.

Western science (WS) follows reductionist and mechanistic approach using scientific method to knowledge production. For instance, in the reductionist approach there exists separation of humans from nature and separation of nature from culture [6]. On the other hand, knowledge production in the IK is through intimate interaction, and holistic relationship between the social and the physical environment. According to [6], it is this connection which provides mutual or harmonious existence and used to develop context specific knowledge. This basic difference in knowledge production either through connection or reduction has its own role in creating power separation which considers a particular knowledge superior to another. In other words, such power separation marginalizes IK as knowledge in development and education sectors.

Accordingly, the Western science is taken as a remedy for every problem that humans face. This trend in relying on Western science marginalizes other ways of knowing that are different from Western perspectives. In addition, Western science provides narrow and perhaps distorted images of nature [7]. Concerning the nature of WS, it is found to be dualistic in approach based on reductionist and mechanistic worldview, objective, universal, dominant, and culture and context free in its representation. This parameter put in place by WS ruled out IK as non-scientific and with no value except in spiritual realm [8]. This nature of WS together with its asymmetric expansion from the center to the periphery makes science as the only means to understand the world [9]. As a result, the

IK of non-Western people is made to be undermined and marginalized not only by the Western world but also by the local people through the influence of school science.

As science is believed to address nature in a mechanistic and reductionist approach, and objectively, those that are beyond such approach are not covered by science. This invites for an attempt to use other ways of knowing (IK) in approaching the world from a different perspective and this helps to come up with complete and holistic solutions to the recurrence of undermining IK. Among sub-Saharan countries, Ethiopia is a country that has its written language with its own unique alphabet and traditional education. The traditional (indigenous) education covers centuries old experiences embedded with either religion or socio-cultural knowledge [10]. Not only these, but people had also designed and built sophisticated obelisks, buildings, walls, statues, monuments, and technologies. The knowledge and skills were created by the local people without any so-called modern knowledge, skill of mathematics, and engineering. Having seen all these, modern education system should have been founded on traditional education and indigenous knowledge of the people to transfer this sense of knowledge creation to the young generation. This could have helped the present generation to spring from the works of her/his forefathers by following their foot prints. As the saying goes, "When you follow in the path of your father, you learn to walk like him" (Ashanti Proverb), albeit the question of extending the gained knowledge. This is made possible if the knowledge and skills were well documented and transferred. However, lack of documentation and influences of the dominant western knowledge caused by various factors affected building the indigenous (traditional) knowledge and technologies to stagger with lack of knowledge transfer.

Local indigenous practices regarding traditional medicines, agriculture, and others are not yet fully studied from the point of view of knowledge transfer. As a result, there is scarcity of literature concerning indigenous ways of knowledge creation and transfer in Ethiopia [10], though knowledge transfer of some indigenous knowledge is accomplished in the form of training [11]. Since IK is largely tacitly stored in the minds of an individual in the form of mental model, it can be exchanged with other individuals through sharing of their experiences in the form of practices. Through enhancing tacit knowledge flow by means of practice involving the interaction of humans (socialization), it is possible to transfer knowledge. Hence, it involves the sharing of experiences through practice that makes it better than knowledge transfer in school science where direct transmission of information is done from a teacher to students.

Knowledge transfer in the IK is in the form of situated learning in that it occurred through participation of trainees in an activity useful for their survival. This goes with the conception of legitimate periphery of learning. In such kinds of sharing knowledge, social interaction is mandatory since it creates a context so that individuals can learn by participating in activities. As the trainee is novice, s/he moves from the periphery to the center through active engagement (legitimate peripheral participation). Finally, s/he will be an expert to perform a task in other words; it is a type of learning through observation and imitation [1]. This is a form of learning through practice or by experiencing the task to accomplish it correctly as observed from the experts. Hence, it is a form of performance-based learning. This paper presents issues that trigger the rethinking of documenting IK as Chiro and indicates the extent of their integration with the school science.

Statement of the Problem

Despite the importance of indigenous knowledge as a foundation for improved learning progression, the indigenous knowledge practices in general and those of traditional medicines, agriculture, and others relevant IKs are not yet fully studied from the point of view of knowledge transfer, and in the Ethiopian context. As a result, there is scarcity of literature concerning indigenous ways of knowing and knowledge transfer in Ethiopia, and the integration of IK in the school science is scanty. In support of this the recent general education curriculum framework of Ethiopia [20] indicates as one of its aims 'utilizing indigenous knowledge and skills for the advancement of the self and the society' (p.4). Nonetheless, Ethiopia is one of the old civilizations in the world that had proven legacies of advancement that could form the base for the need to elaborate IK. To date there is excessive use and dependency on traditional medicines in many parts of the Country. But, either these forms of knowledge are in the minds of individuals or are not in any ways integrated with the school science. This delved the impetus to conduct this study. Since there are wide areas of coverage with respect to traditional medicine, this study tried to limit itself to an area called Chiro.

The objective of this study is to investigate knowledge transfer among elders in Chiro district and to see its implication to science education.

In line with the above objective, the study sought to address the following research question:

1. How does indigenous knowledge transfer look like among elders?
2. What implication does it have to science education?

RESEARCH METHODOLOGY

The study used transformative participatory paradigm (TPP). Researchers concerned with indigenous knowledge usually focused on social justice and transformation. As a result of this relationship between transformative participatory paradigm and Indigenous knowledge, we used the TPP to be appropriate to guide the process of the study. Therefore, we approached the participants from a TPP perspective using sociocultural theory of [12] as a theoretical lens and Ubuntu as conceptual framework. The application of sociocultural theory and Ubuntu helps to have a productive relationship with the participants through respecting their socio-cultural values.

The study employed an exploratory qualitative case study that enables to explore the issue from the participants' perspective and is important to help their voices to be heard. The study area was Chiro. Chiro is in West Hararghe, Oromia Regional State, Ethiopia It is located some 330 km to the east of Addis Ababa. The following are some of the reasons for choosing this study area. First, the area consists of both indigenous and invasive plants including traditional medicinal plants. Second, traditional medicine practices are commonly practiced in the district where I also was one of the beneficiaries. Third, the familiarity of the area to the first author is another criterion since I worked there as a schoolteacher.

The target population encompassed elders (healers and farmers) who are expected to have the required knowledge and skills accumulated through time. Accordingly, five male elders of 50-70 years of age were selected as samples using snowball and purposive sampling techniques. Data collection tools include semi-structured interviews, focus group discussion, field notes, and informal discussions.

Data analysis involves thematic analysis. Conceptual analysis was used to inspect the data to determine the frequency of certain words appearing in a text to be represented as codes and similar codes are clustered together to form categories used to give themes and patterns during relational analysis. The excerpts from the verbatim and field notes are presented based on their potential and representativeness to answer the research questions.

The data are presented in the form of direct quotations and the report on the data were analyzed in a narrative form to present the findings of the research. To ensure trustworthiness we used long terms and repeated observations at the research site and the data were examined repeatedly to ensure the voices are explored exhaustively. In addition, the use of different data collecting methods and member checking and forwarding follow up questions were used to ensure the credibility of the research findings. Debriefing was also used to ensure the credibility of the data. Detail description of the methods used, thick description of the process and the data, and being objective about the data collected are some of the measures which are taken to achieve transferability.

In this research work pseudo names for participants are used to ensure their anonymity and elders are referred as Obbo, as is appropriate to address older people in the Oromic custom. Accordingly, the categories are used as subtopics as seen hereunder.

RESULTS

Apprenticeship Learning

Knowledge transfer to someone they want to transfer is based on community of practice as the following excerpt represents it.

> *The elders ask us to follow while they are going to collect medicinal plants, order us to buy some from the traditional drug shops even from markets after that once we are examined to be trustworthy, they show us how to prepare drugs from a particular medicinal plant and gradually order us to provide patients drugs by preparing according to the dose. By doing so, we can learn first from elders by spending many years and gradually upgrade the skill through experience.* (Obbo Mohammed, 14/1/20)

From the above excerpt, we can understand that knowledge transfer in the IK is through oral explanation and demonstration; hence it is a form of apprenticeship. It involves learning through practice. Informal discussion held with this elder disclosed that: indigenous knowledge transfer has strong link to learning practical skills which are useful to individuals and society [11]. The elders consider certain criteria while they determine to transfer the knowledge to someone up on an old age or illness that risks them to death as follows.

> How could you transfer the knowledge that you have to others?
>
> *Before we transfer the knowledge either to our elder sons or anybody willing to have this knowledge, we examine the character of the individual. And we should ensure that the person is loyal, honest, and can serve the society without abusing them. After we make sure the individual fulfills strong attachment to God and other things, we allow the individual to approach us. In this field you know there are some who are abusing people by asking much money, do harm against others by receiving money from their enemy, etc. Thus we should be more careful in transferring our knowledge but once the individual is found innocent and curious to know the knowledge and is willing to serve the people, we can do whatever we can to help him learn from us*. (Sheikh Jibril, 11/1/20)

As the above excerpt shows knowledge transfer follows certain procedure in TM practices such as being the eldest son, curious to know, being honest, loyal, having a sense of humanity not to harm the society, and being spiritual. Only individuals who can fulfill these criteria are the ones allowed to approach to elders and get trained. Otherwise, they will not transfer the knowledge to any layman. They do this because some irresponsible people who are not developing expertise on the field and pretend to be healers can abuse the knowledge and the people. These irresponsible ones can mislead people without knowing the correct medicinal plant for a particular disease and even they may harm people. By doing so, they probably make the names of true healers to spoil on the eyes of people as a result people may lack trust on the true healers. Due to this reason and others such as the widespread use of allopathic medicines, the number of traditional healers decreased. Not only healers are declining in number but also the knowledge started to dwindle.

As a result, some known healers died without transferring their knowledge fore fearing that these individuals can harm innocent people [13]. This is humanity (Namummaa, Ubuntu) by itself [17]. They want to transfer their knowledge to those who are selected to be true healers by observing their characters such as loyalty, honesty, hospitability, having humanness, spirituality etc. These criteria for an individual to be a healer show that those individuals who can serve the people using MPs and other things like animal parts should exhibit the principles of Namummaa (Ubuntu). As Ubuntu is an African religious and code of conduct or ethical base that healers should exhibit, Namummaa did the same for Oromo people [9]. Those who are robbers and thieves are simply deceiving people to fulfill their self-interest and give priority to their individual interest than the community.

According to an informal discussion held with a participant he said that:

> *If they get the right persons, they take them to the wild where medicinal plants are found and order them to collect and handle the plants following their instruction, bring home and plant in home garden if possible. They tell them which plant and its parts are appropriate for which disease and show them how to take the required parts of the medicinal plants including how to prepare, store, and limit the dose. Gradually when they are sure they developed the required expertise they order them to administer drugs in case of their absence.* (Obbo Mohammed, 14/1/20)

Elders have shared responsibility for training their disciples and learning and on the part of the trainee they are expected to perform by imitating and practicing. Healers ask the trainee to fetch drugs from the local market if the MPs are not found from the wild and help him to develop his knowledge and skill. This is a form of apprenticeship learning through legitimate peripheral participation.

Sometimes when they are absent for some kind of social chores, and when the elder thinks that the trainee is able to deliver the service, he asks him to serve the people seeking the services. Thus, the trainee learns by performing every step starting from collecting MPs, knowing the specific types and their parts, diagnosing the clients up to administration of the drugs. Such knowledge cannot be completed all at once instead it is a lifelong learning so that it is up to the individual to continue improving the knowledge through experience even while he is giving the service, embedding experiential learning.

Such individuals are mostly intelligent and store the tacit knowledge in their own mind and can remember because they have curiosity to think and perform the necessary procedures. They also develop it through continuous engagement. Even when the elder is at home, he orders the trainee to prepare the drugs out of medicinal plants as shown and he is learning by performing it which cannot be forgotten for life. It is a kind of training or apprenticeship where the individual is first approaching the expert, try to fetch something, buy and collect plant materials when ordered by the expert, gradually he starts to do or perform according to the instruction that he has received and begin to do it as the expert did. Finally, though the training is not formal to be awarded with certificate, the trainee can start his own service by improving and researching new methods and new medicinal plants depending on his/her creativity. Social acceptance is also their certification.

Sometimes formal instruction could be given when the trainee makes mistakes [14]. While they are transferring the knowledge it is just a relay, in that the knowledge is transferred in subsequent steps from one generation to other in the form of training, however, knowledge is not transmitted as it is. In each step some improvement is made so that some knowledge is added on it. It is a form of creating new knowledge, at least improvisation. Moreover, indigenous knowledge is not the possession of individuals even if individuals create knowledge, they will make it community's property through sharing or transferring. This is explicated by the next excerpt.

> *Once an individual develops some knowledge or technology, he/she shares among the people, and we discuss about it and if possible, we make some improvement.*

The community's knowledge is kept by knowledge custodians either shared among them or transferred to their disciples through apprenticeship training to make this knowledge part of their daily life. However, the present generation is not willing to heir this time long and valuable knowledge because of generation gap created between old people and youths. Informal discussion with an elder has confirmed that.

> *Only few youngsters are coming to us and show their curiosity to tap this knowledge and we are worried about the future whether the knowledge will continue.*

Their worries are true because as most healers are old people, whenever they die there may not be any one to inherit and pass on the knowledge to the next generation. And it is time to explore and document this valuable knowledge to integrate with modern systems of medicine and science education to ensure its continuity. Science/biology curriculum should create a space for the integration of IK to document and even transfer to the next generation. The inclusion of IK to the formal curriculum is also proposed by the Ministry of Education of Ethiopia.

Above all, it is the responsibility of the youths to inherit it, maintain it, innovate it, and pass to the next generation. As Odora-Hoppers said, it is our wealth, and we should not neglect because it is our heritage [15]. We must respect what we have and develop it to provide the service in a more efficient ways. We have to stop seeking solutions to our problems from others and if possible, we have to integrate it with other knowledge system to get synergy and in this way, we can contribute for the global knowledge economy. However, the young generation undermines this knowledge and seeks solutions for local problems from outside and hate to learn this knowledge as if they become primitive, spurious, and back ward, as they think it to be [16]. But our solutions are at our hands since our problems are different from theirs.

Concerning the traditional knowledge, the learning of this knowledge is lifelong because it is associated with everyday life to be learnt throughout life and is contextual (situated). It is related with the actual life of the elders and elders are responsible to transfer it as they are the custodians [11]. We can infer this idea from the following excerpt.

One of the discussants disclosed that (a developmental agent)

> *We are not in a position to transfer the knowledge; instead, it is the duties of the elders who over time collate more knowledge and skill. And it is a requirement for the young generation to respect, spend time with them and give the required dignity to elders to get the knowledge and skills necessary to make them competent in the community. Elders are responsible to transfer knowledge of the community to the young generation in the form of training.* (Obbo Nuredin, 20/3/20)

According to the above excerpt, elders are responsible to transfer IK to youths. Learning of IK is life long and needs therefore a form of apprenticeship effected by training. It is as such necessary for the young generation to fulfill certain criteria such as respecting elders, spending time with elders, giving the required emphasis to traditional knowledge to be full members of a community and to lead their life accordingly. It is also a sign of respect to ask elders about any knowledge. Thus, youths have to learn competencies as performing traditional medicines and agricultural practices which are knowledge and skills of the community through observation, demonstration, and performing to have meaningful role in the community. Equally important is elders have shared responsibility to train youths on certain competencies that youths are required to have. Youths have to perform practically what are orally explained depending on their age and stages of development. It is usually boys who perform traditional medicines and agricultural practices [11]. Therefore, traditional education is job and gender specific; however, women are also involved in many of the medicinal and agricultural practices even if they are not trained directly like boys. Most learning is done through observation and applying practically so that it is a form of active learning or student-centered learning which participate learners in the whole process of learning and is different from what students are experiencing at school as we can see it next.

Learning by Doing

The involvement of learners in acquiring IK, elaborated above is apprenticeship form of learning. Equally, the engagement seeks learning by doing. Respondents were asked how they transfer their knowledge and skill. In response, one respondent noted:

> *Knowledge is the property of the people, and everybody knows what we are doing here. There is a free flow of knowledge among the community. If somebody discovers something, he/she will show the new thing to the elders and friends, and all involve in discussion about the new thing and devise a means of applying it to the farm and see the result. If the new discovery is fruitful, the whole people will apply it and become the beneficiaries.* (Obbo Seid, 28/3/20)

The above excerpt shows that knowledge is community's property and there is no individual sense of ownership. The knowledge can be transferred by means of demonstration and doing. After its practicality is validated as useful knowledge, it becomes community's property through sharing. Knowledge transfer according to this discussant is open to anyone who needs it as he has dealt about traditional agricultural practices. If it were a traditional medicine practice, it should have been transferred only to someone who fulfills certain criteria. However, elders are responsible to transfer the knowledge because a person with an old age means, he/she knew more than youths so that they have to teach the young generation as they reach the required age.

Here in the rural areas, children perform different activities depending on their age. When they reach the required age to perform agricultural practices, their fathers or elders in the community teach them how to perform the skills which are vital for their later life while they become farmers. However, it was learned that traditional education is gender specific which discriminates youths based on their sex and other contingent criteria. Accordingly, boys and girls are only obliged to do something based on their age to play his/her role as husband and a wife [11]. This is against the contemporary notion of gender equality.

Here teachers are the elders and school is the open environment (under the trees) and education is holistic and prepares the youths for life. Because of this reason trees have values among the local people, they can be places where they discuss and solve their problems individually or communally, serve as sacred places and they serve also as places where people exchange knowledge among each other [17]. And it is the community's responsibility to make youths to be efficient performers of life skill practices such as traditional medicines and farming, behaving in terms of communities' norms, values, and cultures. Unless youths are learning traditional knowledge, it is very difficult to produce people who can maintain the knowledge and skills which are expected of them.

Therefore, elders who are knowledge keepers and transferors should gather girls and boys and teach what they need for future life irrespective of their gender. This can ensure the contribution of both girls and boys to the sustainable life of the community.

Shekh Jibril also expressed his view about how knowledge is transferred as follows.

> *I transfer the knowledge that I have to others if they have a need to know it. You are an example you came to me and told me that you need the knowledge for educational purpose and after I have seen your letter and I became convinced that you will not use it for other purpose and shared you what I know hoping that you will do something good for the promotion of the knowledge in education and it is up to you how to use it.* (Sheikh Jibril, 11/1/20)

The above excerpt shows elders are willing to transfer their knowledge based on willingness and on purpose. They need to know first for what purpose individuals need to use it because there may be people who abuse the knowledge. They need to protect the knowledge from abusers since some individuals abuse the people by acting as true healers where they are not. As a result, elders are committed to transfer their knowledge and skills to those whom they knew very well. He continued to tell that:

> *Here are two people who learn 'Quran' with me and show great interest towards traditional medicine among other disciples. They want to follow my footstep and do whatever I order them and after I have seen their interest and good behavior, I allowed them to observe what I do.*

During the time of the interview, the two disciples were there, listened and saw what the Sheikh was doing. This is how the knowledge is transferred and improved from time to time. Knowledge transfer of the IK is usually done by oral transmission. It is observational by demonstrating their expertise practically and this was evident during the interview which was conducted with the elders. For instance, the community knowledge held at the hands of the elders was exchanged with the interviewer researcher through oral description, explanation, and demonstration. They were demonstrating how they were preparing the drugs, which ingredients are combined at what concentration, what amount is given at a time and at what interval. But the interviewer simply observed without involving in the activities. On the other hand, when it was conducted to others who need to follow their footsteps, they learn by observing, performing, or doing practically what they observed from the elders. Hence, it is a form of learning by doing.

Learning in the IK is practice based embedded with the life of individuals which is different from the formal schooling. In science education, which is confined to classrooms, students are separated from the nature, culture, elders, and the environment and acquire knowledge as fixed but not as wisdom. Indigenous knowledge transfer is purposive in that people become curious to know the local plants and animals based on their use as food, medicines, fuel, etc. This knowledge is usually transferred to others through learning by doing. Therefore, for meaningful science learning to occur, IK has to be integrated with school science to get all the above pedagogical benefits accorded from the IK.

Based on the analysis of data on knowledge transfer one theme was developed from the categories. Accordingly, knowledge transfer is experiential or practical. Thus, the analysis of data showed that the local community contributes a lot to science education in terms of the way knowledge is transferred. As a result, it is better to apply such techniques to science/biology education to enhance its quality and is also an advocacy for the contribution of the local people to biology education by making it contextually relevant and meaningful.

DISCUSSION

The discussion proceeds based on the theme that emerged during the analysis of data. The result of this study is in confirmation with O'ocnnor's explanation in that learning in the indigenous education is related to life-skill training where the trainees are required to observe, imitate, and develop expertise on specific fields by doing [18]. In association to these, the indigenous knowledge transfer is equivalent to project work where the trainees are learning in the outdoor to perform a specific task through practice. As a result, experiential learning is significant to prepare youths for employment because it is job or purpose oriented [18]. During such training, if they do any mistake, they will be given warning followed by formal instruction hence, knowledge transfer includes both informal and formal instructions. Such an education is performance oriented which is accomplished by doing with the involvement of the mind and the sense organs and is hands-on and minds-on.

Since indigenous education is related to the survival of the community, it involves observation, imitation, utilization, and respect to nature [18]. Thus, observation is the first step in knowledge transfer (learning) and next the trainees learn how to perform the task by themselves through repeated practice occurring in an open space. This type of learning is experiential, and learners can make meaning from experts and from their experiences to make it lifelong learning. The result is also in line with Dlamini who explain that while elders train their disciples, they are converting their tacit knowledge to explicit knowledge through observation, oral explanation, and demonstration [19]. This means knowledge is reduced into information that can be codified and easily transferred to others. Through conversion of tacit to explicit knowledge, one can share his/her knowledge to others.

Hence, indigenous pedagogy is experiential accorded with legitimate peripheral approach and through practice-based learning and considers IK as a living process important for their survival [1]. Such a pedagogy unlike the transmissive ways of learning allows a student to explore his/her unique learning style, abilities, and pace of learning [1]. The teaching and learning process in schools did not incorporate indigenous ways of knowing (learning). According to [1], such methods of learning include, observing, listening, and participating with a minimum of intervention and instruction. It is self-controlled or self-regulated learning where students take responsibility for their learning like constructivist approach to learning. In indigenous education, apprentices are directly engaged in learning process by doing under the guidance of experts. Here, learning is not designed to pass examination but to know how to do a specific task and survive because indigenous knowledge is a means of living and a way of being. Therefore, indigenous education which is based on experiential learning is like constructivism [18]. We argue that this form of learning or transferring knowledge should be applicable in science education for students to ensure meaningful learning and to help them transfer their learning into authentic situations.

CONCLUSION AND RECOMMENDATIONS

Indigenous knowledge refers to knowledge attached with everyday life of people who produce it. It is produced based on the worldview and socio-cultural background of people. Indigenous knowledge is tacit which is embedded with practice and experience of individuals and can be transferred with others through tacit knowledge flow, largely converting the tacit to explicit and from knowing to doing. There are few individuals who are knowledge and technology creators. They are specialists who are endowed to make solutions to problems of their generations. Although these individuals create knowledge, through discussion and dialogue (transfer) with other members of a community, they make knowledge the property of people. Regarding traditional medicine, healers consider certain criteria to keep the knowledge from abusers while they transfer the knowledge to someone up on old age or illness that risks them to death.

Knowledge transfer in the IK is done by oral transmission while they are discussing the new idea and is also observational through demonstration of their expertise experientially. Thus, IK is transferred through apprenticeship training and learning by doing which gives it the nature of an experiential learning. Moreover, the indigenous knowledge transfer is job specific meaning it is purposive. Therefore, it is mandatory to integrate IK with science subjects and courses to utilize methods of IK transfer as pedagogical tool for effective science instruction, and to strengthen the link between schools and the community. Indigenous knowledge besides providing contents to science subjects and courses it also contributes in terms of pedagogical (instructional) method to provide PCK for meaningful learning of science.

Hence, it is possible to recommend that indigenous knowledge has to be integrated with science subjects and courses to gain all the benefits of IK.

It is indicated in the recent general education curriculum framework [20] that IK need to be integrated in the school curriculum, but it is wise to explore, organize and document the available IK to be able to integrate meaningful IK that is context relevant and age appropriate.

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LABORATORY EXPERIMENT EDUCATION VIA VIRTUAL SIMULATION DEMONSTRATION DURING COVID-19 PANDEMIC

Chengjun Jiang[1] and Guilin Cheng[2]
1 School of Biological and Chemical Engineering, Zhejiang University of Science and Technology, Hangzhou, China.
2 Academy of Chinese Medical Sciences, Zhejiang Chinese Medical University, Hangzhou, China.
Corresponding author email: jcj312@163.com

ABSTRACT

Considering the COVID-19 pandemic, distance teaching has become a necessity. In some cases, laboratory experiments can be replaced by simulated ones. In this study, virtual simulation experiments were designed for students due to COVID-19 to enhance their learning outcomes. A detailed description of a virtual drug manufacturing process is described. Finally, a survey conducted on undergraduate students' understanding of the process confirmed that the method met their expectations in terms of the knowledge and skills for good manufacturing practice (GMP). *[African Journal of Chemical Education—AJCE 12(2), July 2022]*

INTRODUCTION

The SARS-CoV-2 virus has caused the global COVID-19 pandemic. According to the UNESCO [1], close to half of the world's students are still affected by partial or full school closures. In the past year, approximately 60% of the universities were closed and another 30% experienced major disruptions. In China, distance teaching replaced university face-to-face teaching for around two years, thus affecting nearly 90% of teaching activities across the country. To provide distance learning for theoretical courses, most universities relied on videoconferencing software or on recorded audiovisual materials [2]. Unlike such courses, distance learning in disciplines requiring access to laboratories was not as easy [3,4]. For this, most laboratory experiments were replaced by simulation practices, and the students processed and discussed the obtained data [5-9].

In this report, virtual simulation experiment was conducted for chemical and pharmaceutical engineering majors (www.ilab-x.com) and the method used in this teaching innovation was approved by Zhejiang University of Science and Technology. In addition to this and in accordance with the evolution of the pandemic, the teaching guidelines for chemical engineering degrees have been revised. The practices designed in this study can be used for distance learning during the academic years 2020–21 and 2021–22. The enhancement of virtual simulation experiments will be continued so that they can be used when needed.

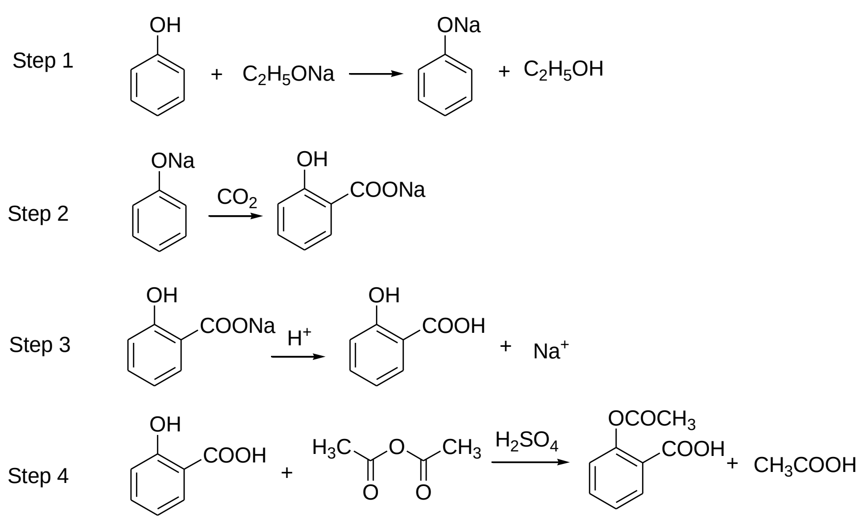
In this project, with the aim of familiarizing new engineering talents with the information technology and optimizing the sharing of teaching resources, the whole process of aspirin production was selected to be performed as a virtual simulation experiment. Three independent parts of the experiment were systematically carried out: aspirin synthesis, tablet preparation, and quality assessment. The application of virtual simulation technology in chemical engineering teaching system allows the virtual visualization of different steps during the process. According to teaching guidelines of the subject, students should master the following points: the common reactions and operations involved in aspirin synthesis, the good manufacturing practice (GMP) requirements for crystallinity, and the requirements of the Chinese pharmacopoeia for the drug quality control. This class aims at developing the students' overall engineering practice ability: their ability to deal with unexpected accidents in the experiment and to understand the GMP standard process, their ability to monitor drug quality and the concept of quality control.

METHODOLOGY

1) Principle of the experiment

The full process of aspirin production by virtual simulation is an experimental project designed to systematically train chemical engineering students. This project uses virtual simulation technology to realize the full production of aspirin. All scenes of the process are virtualized as three operations:

1. Aspirin synthesis. This includes (1) salicylic acid synthesis from sodium phenolate, (2) salicylic acid precipitation, decolorization, and crystallization, and (3) aspirin synthesis and re-crystallization in ethanol for purification. A variety of organic synthesis techniques, such as filtration, distillation, extraction, and crystallization, are used. The detailed procedure according to the Kolbe-Schimitt reaction is as follows: phenol, the starting material, undergoes a reaction with sodium hydroxide to generate sodium phenolate, and then it is heated under pressure with CO_2 to produce sodium salicylate, which is subsequently acidified, recrystallized, and dried to obtain salicylic acid. Thereafter, salicylic acid undergoes an acetylation reaction, followed by decolorization, recrystallization, drying, and other refining processes to obtain pure acetylsalicylic acid, which is the active pharmaceutical ingredient (API) in aspirin. The chemical reaction processes are described in Scheme 1:



Scheme 1 Reaction processes for aspirin synthesis.

2. Tablet preparation. There are various steps in tablet formulation: drying, crushing, screening, mixing, granulation, and compression into tablets. The tablet compression procedure is divided into four stages: filling, dosing (metering), compression, and ejection. A tablet press is the device that compresses the powder into uniform tablets. The filling stage involves placing the blended granules into the punch-die cavity, which is composed of two punches and a die. The two punches are then pressed together with a great force, and the material is combined. In the dosing section, the overfilled or excess granule is removed from the machine, thus the exact weight of the granule is compressed. This exact weight is determined by the lower punch's height, which in turn is determined by the filling can. The dosing scraper scrapes the excess granule from the surface of the die table. In the compression phase, the tablet is formed. The upper and lower punches are brought together within the die under pressure. They move between two wheels, known as the pressure rolls. These rolls push the punches together, resulting in tablet formation. In the final stage, the ejection stage, the tablet is removed from lower punch. The upper punch rises above, thus the lower punch rises in the die. The tablet is pushed outside the die cavity and the takeoff scraper pushes the tablet into the collection container.

3. Quality assessment: As required during tablet preparation, the manufactured tablet undergoes several quality control tests to ensure that it meets certain requirements. The tablets should be complete and clean, with uniform color and appropriate hardness (to avoid fragmentation during packaging, storage, and transportation). They should also have uniform mass, disintegration time, dissolution, and friability. In some cases, the country's pharmacopoeia determines further quality specifications. The drug should comply with GMP specifications.

The basic principle of this experiment is based on the central idea of GMP, aiming at covering teaching needs, professional knowledge, industry terminology and engineering concepts. Modern information technologies are used to promote the actual operations, effectively expand and extend the content of experimental teaching. Modules, including equipment simulation and online learning ones can simulate the whole process of aspirin from production to inspection. Parts of the software operation are shown in Figure 1.

Figure 1. Examples of virtual experimentation.

Students need to complete the synthesis workshop (9 sections, 22 steps), preparation workshop (5 sections, 18 steps), and quality inspection workshop (31 working sections, 16-step operations). A virtualized scene of the whole process of aspirin production on computer has been established to achieve social sharing and maximize the scope of educational audience by independent assessment through internet.

2) Assessment requirements

The assessment is divided into two parts: extended learning and centralized experiment, as showed in Table 1, which are used for the assessment of the step operation and quality control of the simulation software. The assessment requirements of each training program can be customized. Students' performance of specific training programs is evaluated by a scoring system. During the running of training projects, the scoring system will evaluate the corresponding test papers in real time. When the training program is terminated, the scoring system can print out the specific operation details of the corresponding assessment.

Table 1. Assessment requirements

Assessment forms	Assessment contents	Assessment requirements
Extended learning	Aspirin API preparation, tablets, quality check	Pass the relevant test based on GMP of pharmaceutical factory in the text question bank
	SOP operation of formulation workshop	Complete the workshop operation questions in the preparation part of experimental project, and achieve a score of 70 or above in the final assessment
Centralized experiment	Understanding preparation equipment and production operation of API	Time-limited operation: the final completion score is more than 70 points
	Master the standard operation of equipment and production process	GMP related text examination: the final score is 70 points or above

Students can download the experimental client through the experimental website, use their spare time to complete all steps, and synchronize with the online experimental data, finish the text and operation assessment tests under assessment mode. The final score is reflected in the experimental assessment management data, in order to ensure that students have the controllable and executive power to expand knowledge learning.

3) Student survey questionnaire about the virtual simulation experiment in COVID-19 time

To obtain a more objective understanding of how students can better perform virtual simulations, a survey was conducted at the end of the semester to find out what students thought about this kind of education. A total of 120 students enrolled in the course and participated in this online survey and presented their suggestions on this learning method.

Question 1

What do you think are the factors affecting teaching in virtual simulation experiments?

a) Experimental scenario design
b) Experimental teaching content
c) Experimental system stability

Question 2

Do you think that the effect of learning through virtual simulation experiments is better than that through traditional classroom teaching?

a) Better than classroom teaching
b) Similar to classroom teaching
c) Worse than classroom teaching

Question 3

How difficult for the content covered in this experiment?

a) Very difficult
b) Just OK
c) Very simple

Question 4

Do you think that your learning efficiency can be improved by learning through this virtual simulation?

a) Very efficient
b) Just OK
c) Below Average

Question 5

Are you satisfied with the evaluation system of this experiment?

a) Very satisfied

b) Just OK

c) Very dissatisfied

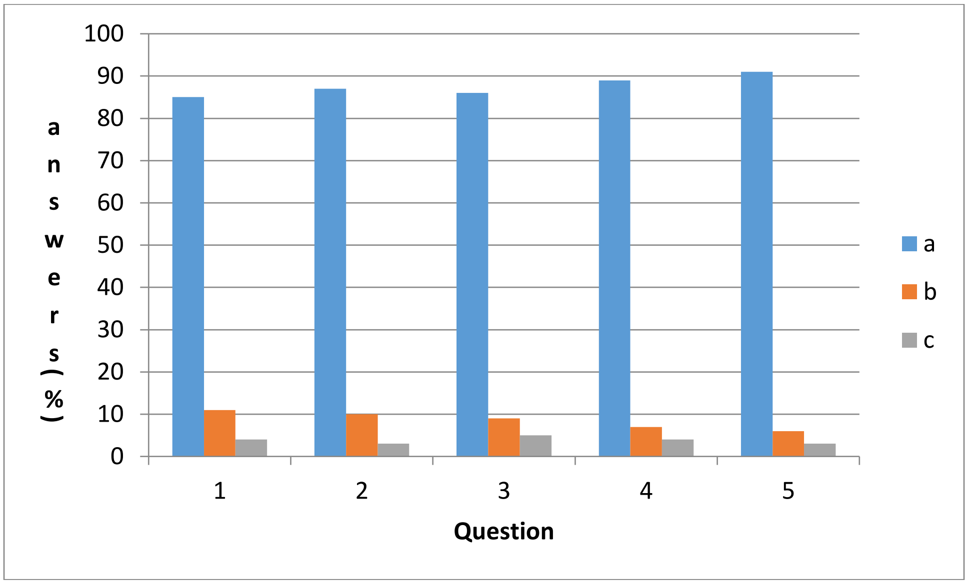


Fig. 2. Results obtained from the survey

These results of the survey revealed that more than 80% of the students were satisfied with this teaching method. Nearly 90% of students believed that virtual simulation experiments were better than traditional classroom teaching. This study also showed the feasibility to replace traditional face-to-face experiments by virtual simulation when needed.

RESULTS AND DISCUSSION

The introduction of virtual simulation experiments in Chemical engineering education greatly affects the learning process of students. Design and application of the virtual simulation teaching technique is fruitful in promoting chemical engineering students' education. However, it is necessary to further optimize the teaching, enrich the content, and build an evaluation system.

Chemical engineering education requires the combination of both theory and application, knowledge transfer and training ability, production practice and scientific research, in addition to compound talent. Therefore, taking advantage of the virtual simulation technology to continuously improve the experimental teaching part is a long-term work, which requires continuous improvement. With the development of the epidemic, especially the rapid spread of the Omicron variant virus, this virtual simulation method will become more and more popular in future education.

ACKNOWLEDGMENT

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THE EFFECTIVENESS OF GUIDED INQUIRY-BASED LEARNING STRATEGY ON LEARNING PHYSICAL AND CHEMICAL CHANGES

Mesfin Berhanu*[1] and Hailu Sheferaw[2]
[1]Kemissie College of Teachers Education, Kemissie, Ethiopia
[2]Bahir Dar University, Bahir Dar, Ethiopia
*Corresponding author email: mesfinberhanu7@gmail.com

ABSTRACT

The purpose of this study was to investigate the effectiveness of guided inquiry-based learning strategy over traditional teaching method in improving grade seven students' learning about physical and chemical change concepts. The participants, N=55 (28 males and 27 females), were seventh grade Sadasa elementary school students in Kemissie town of Amhara regional state, Ethiopia. Quasi-experimental nonequivalent pretest-posttest design was used. Two classes (groups) from the school were randomly selected from four available classes (groups). The experimental and control group was assigned after their pretest was analyzed. The experimental group was taught by guided inquiry-based learning strategy while the control group was taught by traditional teaching method. Open ended questions related to physical and chemical changes were administered as pre- and post-tests to students in both groups. Furthermore, structured interview was conducted to students in the experimental group at the end of the study in order to get students' attitudes about guided inquiry-based learning strategy. The pretest and posttest data were analyzed by using independent samples t-test and paired samples t-test. The students' interview about guided inquiry-based learning strategy was transcribed and then analyzed. Independent samples t-test revealed that experimental and control groups were scored almost similar before the intervention. After the interventions, independent samples t-test and paired samples t-test analysis indicated that students in the experimental group scored significantly higher than in control group. Thus, guided inquiry-based learning strategy was more effective to improve student's achievements in physical and chemical changes concepts than traditional teaching method. Thematic analysis indicated that students in the experimental group demonstrated high level of interest and positive attitudes toward the guided inquiry-based learning. *[African Journal of Chemical Education—AJCE 12(2), July 2022]*

INTRODUCTION

Chemistry is the study of the structure, properties, and uses of matter. Chemistry plays important roles in everyday life. Despite its importance, many factors make chemistry difficult to learn. Among the factors affecting the students' learning of chemistry are teacher-centered method of teaching and the abstract concepts of chemistry [39]**.** Most Chemistry concepts have proved to be difficult for students. In particular, the concept of physical and chemical changes considered difficult for students. [61] explored students' difficulties in physical and chemical changes. Students have different conceptions on the topic of physical and chemical changes. For example, [23] identified few of students had scientific conceptions and most of them had partial conceptions and alternative conceptions.

Researchers criticize that teacher-centered approach of teaching is ineffective in comparison to inquiry-based learning [1]. For this reason, teachers need to design appropriate instructional approaches to overcome students' misconceptions related to physical and chemical changes. Effective strategies for some topics in chemistry include inquiry-based learning. Research findings show that inquiry-based learning was more effective in enhancing students understanding of electrochemistry [54][57][50] chemical reaction rate [56] acid-base [55] chemical equilibrium [49]. Additionally, simulations have been shown to increase students' achievements [53]. Studies on the topic of physical and chemical changes showed that using word association test was more effective in revealing students' cognitive structure and their misconceptions [62]. Results from experimental studies on the topic of physical and chemical changes identified teaching students with animation enhanced worksheet-based instruction was more effective in enhancing students' understanding and overcoming alternative conceptions than traditional way of teaching [32].

Multimedia-based instruction improved students' understanding of particulate representation related to chemical change [4]. Furthermore, experimental studies on the topic of physical and chemical changes reported that utilizing student centered teaching method was more effective in improving students' understanding of these topics than using traditional teaching method. For instance, teaching this topic through jigsaw cooperative teaching [59], science writing heuristic approach [31], storylines embedded within context-based learning approach [17] improved their understandings.[19][51] showed that guided inquiry-based learning improved students' achievements and understanding. Physical and chemical changes require critical thinking of students rather than memorizing. Inquiry based learning possess more advantage over traditional teaching method. For instance, [43] reported that process oriented guided inquiry-based learning enhanced six grade Southern Turkish students' achievement in the "particulate nature of matter concept and density concept." However, there was no difference in the achievement between experimental group who taught through process oriented guided inquiry-based learning pedagogy and control group who taught through teacher centered whole-class instruction related to "physical and chemical change concept." But what is not yet clear is the effectiveness of guided inquiry-based learning on the achievement of students related to physical and chemical changes. Therefore, the purpose of this study was to investigate the effectiveness of guided inquiry-based learning over traditional teaching method in enhancing seventh grade students' achievement related to the conceptualization of physical and chemical changes, which are not yet common in Ethiopian schools.

Statement of the Problem

Many of the students were not able to distinguish physical change from chemical changes [29]. For example, a lot of students had misconceptions because they "treated chemical changes such as rusting as physical changes in form or state" [25], "The candle wax in a burning candle is not burning, but only melting"[10] as cited in [45], and "Terms such as *evaporation* and *burning* can be used interchangeably when describing burning alcohol" and "Phrases such as chemical change and physical change can be used interchangeably when describing burning things"[12] as cited in [45]. Students have different conceptions on the topic of physical and chemical changes. For instance, [23] asked students from first year senior high school in Ghana to explain the concept of physical changes. Their responses indicated that 32% of the students were able to explain aligned to scientific consensus, 32% of them had partial conception and 36% of them had alternative conception. Similarly, students explained the concept of chemical changes.

The result showed that 32%, 38% and 30% had sound conception, partial conception, and alternative conception respectively. This demonstrated student had high partial conceptions and alternative conceptions regarding physical and chemical changes. [61] explored students' difficulties in physical and chemical changes. Many of the students had low achievements in chemistry in Sadasa elementary school. However, understanding the concepts of physical and chemical changes is important in everyday life because matter change in everyday life. Inadequate understanding of these concepts make failing to know the changes happens in matter. For this reason, more research is required to overcome students' difficulties and misconceptions related to physical and chemical changes. Therefore, this study, tried to fill this gap by forwarding the following leading research questions.

Research Questions

1. Is there a statistically significant difference between the mean scores of the experimental and control group on pretest achievement?
2. Is there a statistically significant difference between the mean scores of the experimental and control group on posttest achievement when guided inquiry-based learning strategy and traditional teaching method is used related to physical and chemical changes?
3. Is there a statistically significant difference between the mean scores of pretest and posttest for both experimental and control group?

4. What attitudes are developed on the parts of the seventh-grade students about guided inquiry-based learning strategy after they learned physical and chemical changes within this method?

General Objectives of the Study

The general objective of this study was to know if there is any difference in students' achievement when the physical and chemical changes concepts of chemistry are taught using the guided inquiry-based learning strategy and when taught using the traditional teaching methods at the Sadasa grade seven elementary school in Kemissie in Ethiopia.

Specific Objectives of the Study

1. To compare the relationship between the mean score of experimental and control group on pretest achievement.
2. To investigate the effectiveness of guided inquiry-based learning strategy over traditional teaching method in improving seventh grade students' achievement related to physical and chemical changes.
3. To compare the relationship between the mean scores of pre-test and posttest for both experimental and control group to check the significance difference between the two performances.
4. To explore students' attitudes about guided inquiry-based learning strategy after they learned physical and chemical changes within this approach of teaching.

THEORETICAL FRAMEWORK OF THE STUDY

The theory used in this study was the Bybee 5E learning cycle model [14] which is an inquiry-based learning approach. The 5E learning cycle model sequences learning experiences so that students can construct their understanding of a concept during the teaching and learning process [14]. The model leads students through five phases of learning that are easily described using words that begin with the letter E: Engagement, Exploration, Explanation, Elaboration, and Evaluation. Bybee's 5E learning cycle model is represented in Figure 1.

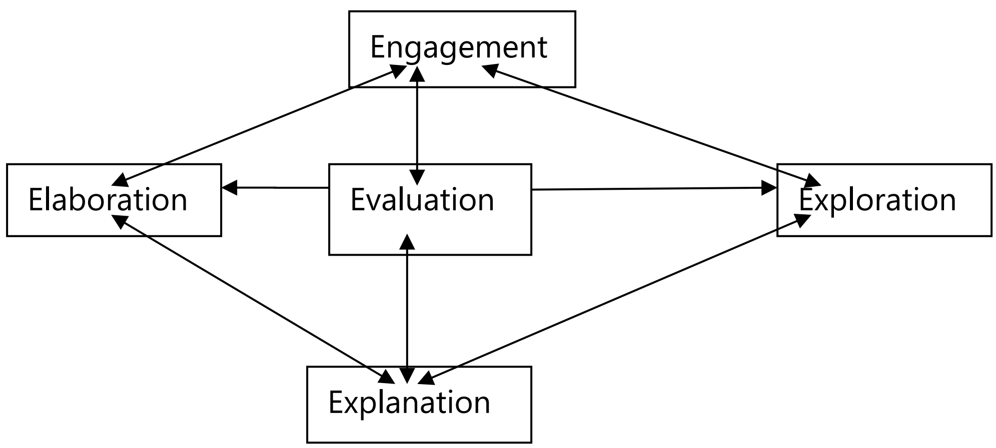

Figure 1: Bybee 5E learning cycle model

Inquiry Based Learning

"A definition of inquiry-based learning is not clear-cut" [40]. Inquiry learning 'refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world' [35]. National research council describes inquiry as ‘a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze and interpret data; proposing answers, explanations and predictions; and communicating results’ [2].

> **“**Other definitions encompass processes, such as using investigative skills; actively seeking answers to questions about specific science concepts; and developing students’ ability to engage, explore, consolidate, and assess information’’[16].

> “Students engaged in simple inquiry engage in processes such as observing, comparing, contrasting, and hypothesizing. Students engaged in full inquiry use these skills in the context of well-structured, science-subject-matter knowledge and the ability to reason and apply scientific understanding to a variety of problems” [16].

Inquiry teaching is defined as ‘providing a classroom where learners can engage in scientific oriented questions to formulate explanations based on evidence’ [35].

Types of Inquiry

Different authors have developed different classifications of inquiry-based learning. But this study focuses on [58] classification of inquiry-based learning. [58] classified inquiry-based learning as follows:

a. **Confirmation**. The teacher tells students the outcome of a problem and gives instructions on how to carry out an experiment or investigation in order to confirm the outcome.

b. **Structured inquiry**. Students are given a structured step by step process in how to investigate a given prompt or question.

c. **Guided inquiry**. The teacher gives a prompt or questions as a starting point, and students find their own way to answer the question.

d. **Open inquiry**. Students initiate their own questions and formulate their own processes to answer their questions.

Guided Inquiry Based Learning

In guided inquiry-based learning, the teacher provided the question for the students and students find their own way to answer the question. For example, table 1 demonstrates the role of teacher and students during the implementation of guided inquiry-based learning strategy in the classroom [21].

Table 1: The role of teacher and students during the guided inquiry-based learning

Type of inquiry	Questioning	Planning	Implementing	Concluding		Reporting	Applying
GIBL	Teacher	Students/ teacher	Carrying out plan	Analyze Data	Draw Conclusions		
			Students	Students	Students	Students	Students

RESEARCH DESIGN

This study applied quasi-experimental design nonequivalent pretest-posttest control group. Two naturally occurred classrooms (groups) were randomly selected from four available classes. The experimental and control group were assigned after their pretest was analyzed. It involves random assignment of intact groups (classes) to experimental or control group, not random assignment of individuals [22]. According to [24] "obtaining pretest measurements for both the intervention and control groups allows one to assess the initial comparability of the groups. The assumption is that the smaller the difference between pretest measurements, the less likelihood there is of there being important confounding variables between the 2 groups." After the intervention, both groups took posttest. The experimental group was taught through guided inquiry-based learning strategy and the control group was taught by traditional teaching method. Table 2 demonstrates the design of the study [5].

Table 2: Nonrandomized control group, pretest-posttest

Group	**Pretest**	**Treatment/intervention**	**Posttest**
EG	Y_1	X	Y_2
CG	Y_1	-	Y_2

Note: EG: experimental group, CG: control group, Y_1=pretest, Y_2=Posttest, X=treatment

Research Setting and Targets

The study was conducted in Kemissie town in grade seven Sadasa elementary school. The population of this study was 135 grade seven Sadasa elementary school students. The Sadasa elementary school was selected by the researcher purposefully because this school has many students.

Table 3: Population and sample size distribution in Sadasa elementary school, Kemissie town

Name of school	Total population			Samples size					Description
	M	F	T	M	F	T	Grade	section	
Sadasa elementary school	70	65	135	14	14	28	7	A	Experimental group
				14	13	27	7	D	Control group

Sources: School report

Source of Data

The researcher used primary data to get information. Two groups (classes) were randomly selected by using lottery method from four available groups (classes) due to all classes were equivalent in terms of achievements in chemistry before the study. The data was obtained from grade seven students' one experimental and one control group by using physical and chemical changes achievement test and students were interviewed about their conceptions on the guided inquiry-based learning strategy. The participants (N=55) were seventh grade elementary school students aged 11- 17. Generally, grade 7 “A” and “D” students’ were the primary data source of this study.

Data Collection Methods

To determine the effectiveness of guided inquiry-based learning strategy on the achievement of students’ concerning physical and chemical changes concepts two instruments were used: (i) the physical and chemical changes open-ended questions was used as pre- and post-tests to students. (ii) Structured interview about guided inquiry-based learning strategy was conducted to the students. For the interview about the effectiveness of guided inquiry-based learning strategy, open-ended questions were adapted from the studies of [60][7]. Students from high score N-gain, medium score N-gain and low score N-gain [6] were selected purposively (maximum variation sampling) from experimental group for structured interview.

Teaching Method

In order to control the confounding variables, the teaching-learning process in both groups were conducted by one teacher (the researcher). Students’ score on this topic was similar as analyzed from their pre-test. Most of the hands-on activities are found in the students’ textbook except some concepts that got less consideration in the book. Therefore, in both groups the same material: students’ textbook and diagrams depicting physical change and chemical change were used. The same content was covered in the experimental group as in the control group. The teaching-learning process accompanied for two weeks, which is three days per week, and 40 minutes for each contact.

Teaching Method in the Control Group

The students in the control group were taught by the teacher (researcher) of this study using traditional teaching method such as telling how to do the experiment step-by-step, demonstrating, verbal explanation, defining concepts, text materials, lectures, and questioning and answering to the whole class. The teachers' role was to demonstrate the experiments, to transfer the facts, and concepts to students. During the teaching-learning process, students acted as passive listeners and observing the experiment. At the same time in these classes the teacher also asked questions without creating discussions. In some cases, students failed to respond to the questions. In this case, the teacher gave the answer to the question. In the control group, the students were only motivated by teacher directed questions; there were hands on activities done only by the teacher and no group work in class during the teaching of the topic physical and chemical changes.

Teaching Method in the Experimental Group

The teacher (researcher) of this study taught the student in the experimental group using guided inquiry-based learning strategy in the small group. The researcher divided the students into smaller cooperative groups of four and questions were distributed for each group. The students were given a hands-on activity and they conducted an experiment. Students recorded their observations from the experiment. Students communicated their observations and reported their finding to the class. Students applied their macroscopic findings from the experiment to the submicroscopic level by interacting with drawings or picture representing physical and chemical change.

Students were evaluated regarding their understanding by means of listening student's reflections, observing students' discussion and discussing related questions with students in the class. In general, the researcher treated the experimental group according to the figure 2 at the time of implementation of the lesson plan in the classroom.

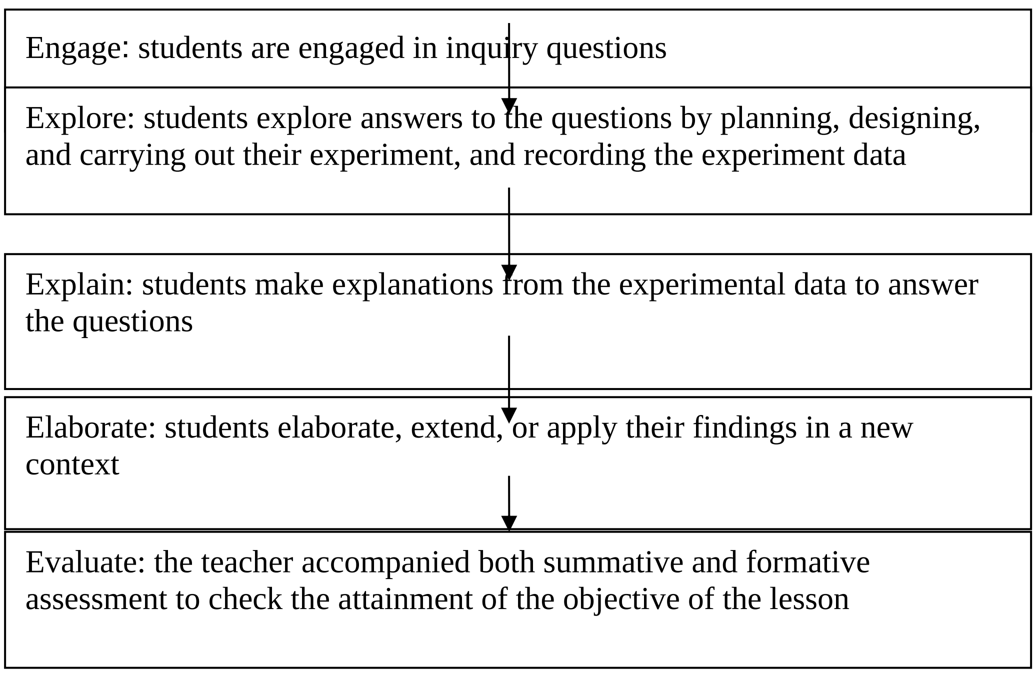

Figure 2: Diagram of guided inquiry-based learning strategy

Description of the Concepts Related to Physical and Chemical Changes in the Classroom

The teacher (researcher) planned a lesson plan on the concepts of physical and chemical changes such as melting of sulphur, burning magnesium ribbon, burning candle, rusting of iron nail, and fermentation of sugar. In each lesson plan the following table 4 describes the learning activity in both experimental and control groups in the classroom.

Table 4: Key learning activities of physical and chemical changes in the classroom

content	**macroscopic representation**	**sub-microscopic representation**	**time**
physical changes (melting of Sulphur) main question: what has happened to the Sulphur when heated?	observing the color and state (form) of Sulphur before and after melted	diagrams depicting physical change	40’
chemical changes (burning magnesium ribbon) main question: what has happened to the magnesium ribbon when burnt?	observing the change in color, state, appearance and ductility before and after burning	drawing or picture depicting chemical change	40’
physical and chemical changes (burning candle) main question: what has happened to the candle when burnt?	observing the change in size, state and appearance before and after burning	drawing or picture depicting physical and chemical change	40’
chemical changes (rusting of iron nail) What happens when iron nail is exposed to moisture?	observing the change in the color, and texture before and after iron nail exposed to moisture	drawing or picture depicting chemical change	40’
chemical changes (fermentation of sugar) What happens when you add sugar to yeast?	observing the change in odor and volume of balloon before and after sugar is added to yeast	drawing or picture depicting chemical change	40’

Validity and Reliability of the Instruments

The test was developed by researcher based on Bloom's taxonomy. Advisor, classroom teacher, and researcher were validated the content of the tests item in pretest. The test was piloted with a sample of 23 (15 females and 8 male) seven-grade students to determine item difficulty, item discrimination and the reliability (Cronbach alpha) by using the formula adopted from [47]. After the item analysis, ten items were eliminated. The item difficulty (p) for each item was in the range of 0.41-0.54, the discrimination index (r) for each item was in the range of 0.5-0.91 and the reliability based on Cronbach alpha for the entire test was 0.816.

Data Analysis

The respondent's replays for the test (pretest and posttest) and for the interview (see appendix A) were analyzed in quantitative and qualitative method respectively. For the physical and chemical changes open-ended questions, descriptive and inferential statistics were used via Statistical Package for the Social Sciences (SPSS version 20). Regarding the descriptive statistics analysis, the mean and standard deviation were calculated in experimental and control groups. Concerning inferential statistics analysis, independent samples t-test and paired samples t-test were conducted for the pre-test and post-test scores to determine the effectiveness of guided inquiry-based learning strategy (independent variable) on achievement of students' concerning physical and chemical changes concepts (dependent variables). All statistical analyses were performed at the 0.05 significance level. For the Interview about guided inquiry-based learning strategy open-ended questions, students' responses on the interview were transcribed and then thematic analysis was conducted.

Table 5: The criteria of scoring the physical and chemical changes open ended questions for each item

score	Level of understanding	Criteria for scoring
1	Sound Understanding: (SU)	Explanations with all concepts corresponding to both scientific consensus and scientific concepts of scientists
0.75	Partial Understanding: (PU)	Explanations with at least one concept corresponding to scientific consensus and scientific concepts of scientists
0.5	Partial Understanding with Specific Misunderstanding: (PU+MU)	Explanations with at least one concept corresponding to scientific consensus and scientific concepts of scientists but partially alternate to scientific concepts
0.25	Specific Misunderstanding: (MU)	Explanations with no concept corresponding to scientific consensus and scientific concepts of scientists
0	No Understanding: (NU)	Explanations with no detail or no scientific concepts scored 0 point and were defined as "No Understanding

Source: adopted from [57]

Ethical Issues of the Study

Permission from the school director and classroom teacher were received in order to conduct the study in the schools. Two groups or classes were permitted to participate in the study. The data collections were carried out based on the willingness of study population. Every information including the name of participants were kept secret and seen only by the researcher. Subjects or participants can ask any unclear questions whenever.

RESULTS

Quantitative Data Analysis

Using an independent t test and paired t test the following results were obtained.

Table 6: Results of descriptive statistics for pretest scores

Test	Group	N	M	SD	SE
pretest	EG	28	5.0268	3.10043	0.58593
	CG	27	4.0278	3.35076	0.64485

Table7: Results of independent t test for the pretest scores

Test	**F**	**t**	**df**	**p**	**P(2 tailed)**
pretest	0.209	1.148	53	0.650	0.256

Physical and chemical change achievement pretest analysis for experimental and control group given on table 7 shows there was not a significant difference found between the two groups at t value 1.148 as p value 0.256 was greater than 0.05. The mean pretest and their standard deviation for both experimental and control groups given in table 6 is (M = 5.0268, SD = 3.10043) and (M = 4.0278, SD = 3.35076) respectively. Therefore, at p=0.05 both groups are similar.

Table 8: Results of descriptive statistics for posttest scores

Test	Group	N	M	SD	SE
Post-test	EG	28	6.8304	2.65366	.50149
	CG	27	4.3426	2.90817	.55968

Table 9: Results of independent t test for the posttest scores

Test	**F**	**t**	**df**	**p**	**P (2 tailed)**
Post-test	0.425	3.316	53	0.517	0.002

According to hypothesis 1 there is no statistically significance difference in students' achievements between the experimental (those who were taught through guided inquiry-based learning strategy and control group (those who were taught through traditional teaching method) on posttest scores at p= 0.05. Physical and chemical change achievement posttest analysis for experimental and control group given on table 9 shows there was a significant difference found between the two groups at t value 3.316 as p value 0.002 was less than 0.05. The mean posttest and their standard deviation for both experimental and control groups given in table 8 is (M =6.8304, SD = 2.65366) and control group (M = 4.3426, SD =2.90817) respectively. The experimental group scored 0.84 higher than the control group (effect size = 0.84). Therefore, hypothesis 1 which says there is no statistically significance difference in students' achievements between the experimental (those who were taught through guided inquiry-based learning strategy and control group (those who were taught through traditional teaching method) on posttest scores at p= 0.05 is rejected.

Table 10: Paired samples correlations of pretest and posttest for experimental and control groups

Group		**N**	**correlation**	**Sig(p)**
EG	Pretest-posttest	28	0.887	.000
CG	Pretest-posttest	27	0.760	.000

Table 10 showed that there was a correlation between the pretest and posttest achievements of students in the experimental group with a correlation value 0.887 as statistical p value of (p=0.000<0.05) and there was a correlation between the pretest and posttest achievements of students in the control group with a correlation value 0.76 as statistical p value of (p=0.000<0.05).

Table 11: Paired samples statistics for experimental group

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	pretest	5.0268	28	3.10043	.58593
	posttest	6.8304	28	2.65366	.50149

Table 12: Paired samples statistics for control group

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	pretest	4.0278	27	3.35076	.64485
	posttest	4.3426	27	2.90817	.55968

Table 13: Results of paired t test for the experimental and control groups on pretest and posttest

Group		**Paired differences**			**t**	**df**	**p**
		M	SD	SEM			
EG	Pair1 pretest Posttest	-1.80357	1.43268	.27075	-6.661	27	.000
CG	Pair1 pretest Posttest	-0.31481	2.20750	.42483	-0.741	26	0.465

According to hypothesis H_2: There is no statistically significance difference between the mean scores of pretest and posttest for both experimental and control group ($p<0.05$). The paired samples t test analysis given in table 13 indicates that there was a significant difference found between the mean score of pretest and posttest for experimental group at t value -6.661 as p value 0.000 was less than 0.05. The mean scores of pretest and posttest and their standard deviation for experimental group given in table 11 is (M =5.0268, SD =3.10043) and (M =6.8304, SD =2.65366) respectively. Therefore, at p=0.05 level the null hypothesis is rejected for experimental group. The paired samples t test analysis given in table 13 indicates that there was no a significant difference found between the mean score of pretest and posttest for control group at t value -0.741 as p value 0.465 was greater than 0.05. The mean scores of pretest and posttest and their standard deviation for control group given in table 12 is (M =4.0278, SD =3.35076) and (M =4.3426, SD =2.90817) respectively. Therefore, at p=0.05 level the null hypothesis is accepted for control group.

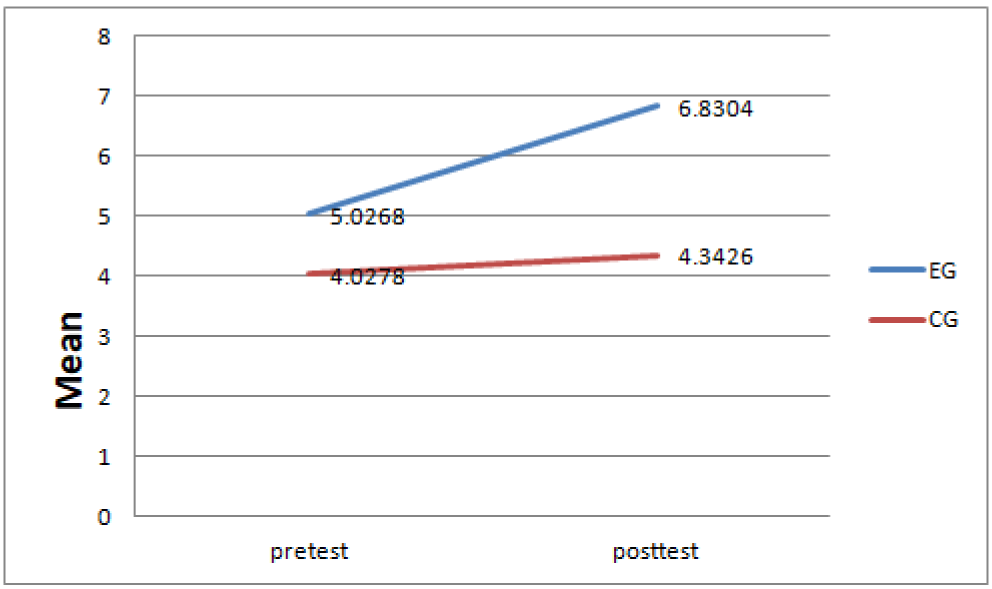

Figure 3: Graph of posttest mean scores in comparison to pretest mean scores for experimental and control groups

Figure 3 indicates that the mean achievement score of experimental group in pretest is 5.0268 and in posttest 6.8304. The mean achievement score of control group in pretest is 4.0278 and in posttest 4.3426. This shows that the achievement score of experimental group is better than the achievement score of control group on the posttest.

Qualitative Data Analysis

Table 14: Themes and codes for students' views about guided inquiry-based learning strategy

Theme	code	Samples	f	%
Students' perceptions about the effectiveness of Guided inquiry-based learning strategy	Effective	I was interested in as I could understand easily the difference between physical and chemical changes. Therefore, it was effective	4	100%
Students' interest to the guided inquiry-based learning strategy	Interested	I was interested when the teacher asks questions and I answered the questions by doing experiment	4	100%
Difficulties students encountered during the guided inquiry-based learning strategy	Difficulty	I encountered difficulty when some students disturb	1	25%
	No difficulty	There was no difficulty we encountered	3	75%
Students' perceptions about the teacher's role during guided inquiry-based learning strategy	Helping students	The teacher helped, motivated us to do experiment and answer questions	4	100%

After the intervention, the experimental group students' views about guided inquiry-based learning strategy were collected through structured interview were analyzed in thematic analysis to answer the fourth research question. Thematic analysis indicated that four essential themes were developed: Students' perceptions about the effectiveness of guided inquiry-based learning strategy, students' interest to the guided inquiry-based learning strategy, difficulties students encountered during the guided inquiry-based learning strategy, and Students' perceptions about the teacher's role during guided inquiry-based learning strategy. The thematic analysis is presented one by one in the following subsections as a, b, c, and d.

(a) Students' perceptions about the effectiveness of Guided inquiry-based learning strategy

Students' views about the effectiveness of guided inquiry-based learning strategy were examined in one theme: It is effective. 100% of the students thought that guided inquiry-based learning strategy was effective in gaining deeper understanding. They explained that guided inquiry-based learning strategy provided experimentation and appropriate questions. For example, one of the students stated that: "I was interested in as I could understand easily the difference between physical and chemical changes." For different student, "Learning by doing experiments made me advantageous." Therefore, guided inquiry-based learning promotes higher order thinking skills.

(b) Students' interest to the Guided inquiry-based learning strategy

The entire students 100% reported that, "We liked to do experiments during the guided inquiry-based learning strategy." For instance, one of the students said that: "I was interested in learning by being asking and answering and doing the experiment." For another student: "I was interested when the teacher asks questions and I answered the questions by doing experiment."

(c) Difficulties students encountered during the Guided inquiry-based learning strategy

Students' views on the difficulty they encountered were analyzed in two themes: no difficulty and there was difficulty. Most of the students 75% expressed that they did not encounter any difficulties during the implementation of guided inquiry-based learning strategy; the rest students (25%) expressed that they had some difficulties during guided inquiry-based learning. Those who stated that there was a difficulty indicated one causes. That cause was: ''I encountered difficulty when some students disturb."

(d) Students' perceptions about the teacher's role during Guided inquiry-based learning strategy

Students' perception about the teacher's role during guided inquiry-based learning strategy was analyzed in one theme. All of the students 100% described that the teacher asks questions during the teaching and learning process. As an illustration, one of the students said that: "Because the questions the teacher asks are related to the experiment we did, it makes the lesson easy and clear for us."

DISCUSSION

The purpose of this study was to investigate the effectiveness of guided inquiry-based learning strategy over traditional teaching method in improving seventh grade students' achievement related to physical and chemical changes. Independent t test indicated that before the intervention there was no statistically significance difference between the mean score of experimental group and control group when compared on pretest. This showed that before intervention both groups are similar in the physical and chemical changes concepts. However, the independent t test and paired t test showed that after the intervention the students who were learned through guided inquiry-based learning strategy achieved better than the students who were learned through traditional teaching method on posttest on physical and chemical changes. Students who were taught by guided inquiry-based learning strategy illustrated significantly higher scores on the physical and chemical changes concept test than those who were taught by traditional teaching method. Particularly, this study indicated that the guided inquiry-based learning strategy was more effective than traditional teaching method to increase students' achievements in physical and chemical changes concept.

Therefore, this study supports the existing studies that showed the effectiveness of guided inquiry-based learning strategy over traditional teaching method [6]. Because in the experimental group students were mentally and physically active, the students establish relationships, observe patterns and identify variables [14]. In the previous studies, it is understandable that inquiry-based learning was more effective in enhancing students understanding of chemistry subject[54][57][50][56][55][48]. However, this study is contradicting with some of the results of previous studies conducted in the effect of process oriented guided inquiry-based learning pedagogy on the students' achievement in physical and chemical change. For instance, [43] reported there was no difference in the achievement between experimental group who taught through process oriented guided inquiry-based learning pedagogy and control group who taught through teacher centered whole-class instruction related to "physical and chemical change concept.

Different from this study, the present study provided the effectiveness of guided inquiry-based learning in enhancing students' achievement in physical and chemical changes. In the experimental group of this study, Students were engaged in scientific oriented questions to formulate explanations based on evidence' [35]. In the experimental group students engage in discussions and information seeking activities [14]. The students in the control group were passive during the traditional teaching method. Students acted as passive listeners and the teacher was demonstrating the experiments, transferring the knowledge and concepts to the students. This brought the students low achievements in physical and chemical changes test in the control group. Nevertheless, during the guided inquiry-based learning the hands-on activities provided the students with better achievements in physical and chemical changes test in the experimental group. Students in the experimental group was making observations; posing questions; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze and interpret data; proposing answers, explanations and predictions; and communicating results' [2].

Thus, guided inquiry-based learning strategy helped the students to construct their own knowledge. Above all, physical and chemical changes are one of the chemistry topics which students were not able to distinguish physical change from chemical changes [29][25][45][23][61]. [25] proposed that students commonly experienced difficulties at three different epistemological levels: chemical knowledge (failed to invoke atoms and molecules as explanatory constructs, even though they had been emphasized in their chemistry course. Some students also listed "substances" such as heat, cold, or decay as reactants or products), conservation reasoning (many students could not predict or explain mass changes in the chemical reactions. Their most common problems included (a) a tendency to treat chemical changes such as rusting as physical changes in form or state, and (b) failure to understand the role of invisible (in this case gaseous) reactants or products in the reactions), and explanatory ideals (many students demonstrated a preference for explanations based on superficial analogies with everyday events (e.g., rusting is like decay) over explanations based on chemical theories). Concerning to this students' difficulty, this study shows that the guided inquiry-based learning provided an effective learning strategy that increases students' understanding and achievement. Moreover, analysis of students' attitudes through thematic analysis about guided inquiry-based learning that was collected by structured interview indicated that the students taught with the guided inquiry-based learning had positive attitudes about the guided inquiry-based learning. They expressed that the lessons are more interesting and understandable. Further, they specified that the importance of asking questions and experimentation during the teaching and learning process. This finding supports the previous study that showed students had positive attitudes towards guided inquiry-based learning strategy [9][42][7]. Therefore, from this finding one of the positive factors influencing students' attitudes toward chemistry learning is using guided inquiry-based learning. The guided inquiry-based learning provided for the students' deeper understanding of the concepts and enhances their attitudes towards chemistry learning.

For this reason, Students in the experimental group had positive attitude towards learning and high interest due to the usage of guided inquiry-based learning. This study opposes some of the results of previous studies conducted in the effect of 5E inquiry learning activities on the students' attitude in chemistry. For example, [48] showed that there was no statistically significant mean difference between experimental and control groups with respect to attitude toward chemistry. However, the present study provided evidence for the students had positive attitudes towards guided inquiry-based learning during chemistry learning. The students taught with guided inquiry-based learning showed that more interesting and motivated during chemistry lesson.

The application of guided inquiry-based learning strategy in classroom has various implications for students. Learning through guided inquiry-based learning strategy enhances students' achievement in chemistry. Students are able to achieve better conceptual understanding of the physical and chemical changes. It is possible to overcome students' alternative conceptions regarding physical and chemical changes through guided inquiry-based learning strategy. It can increase the skill of doing experiments and make understandable. It can encourage students to construct knowledge by themselves. Additionally, students' attitudes towards learning were increased, specifically on the topic of physical and chemical changes. Therefore, from this study it is possible to claim that guided inquiry-based learning strategy was more effective than traditional teaching method.

CONCLUSIONS

The main purpose of this study was:

- To determine the difference in students' achievement when the physical and chemical changes concepts were taught using the guided inquiry-based learning strategy compared to the traditional teaching method at the grade seven Sadasa elementary school in Kemissie town in Ethiopia.
- To explore students' attitudes about guided inquiry-based learning strategy after they learned physical and chemical changes within this approach of teaching.

As demonstrated in chapter one, many students had misconceptions and low achievements related to the physical and chemical changes concepts. To determine the effectiveness of guided inquiry-based learning strategy over traditional teaching method in chemistry lessons, the quasi-experimental design nonequivalent pretest-posttest control group was used. The teacher-centered method of teaching is one of the factors affecting the students' learning of chemistry and the abstract concept of chemistry is the other factor [39].

Therefore, the main results of this study include the following:

- Students who were taught through guided inquiry-based learning strategy performed better than those who were taught through traditional teaching method on posttest.
- Students in the guided inquiry-based learning strategy had positive attitudes and more interested.
- Effect size was larger for the achievements of students who were taught through guided inquiry-based learning strategy that demonstrates guided inquiry-based learning strategy was better than traditional teaching method.
- The result of thematic analysis indicated that students who were taught through guided inquiry-based learning strategy showed more interested and motivated.
- Thus, guided inquiry-based learning strategy was more effective to improve student's achievements in physical and chemical changes concepts than traditional teaching method.

In this study the individual students were not randomly assigned to the experimental and control groups because the school principal had already formed the classrooms which did not permit to assign individual students to either experimental or control groups randomly. Therefore, this study randomly assigned intact groups (classes) to experimental or control groups. This study has no information about how guided inquiry-based learning strategy influence students' achievements in different populations and settings since the study was limited to grade seven Sadasa elementary school in Kemissie town. This limited the study due to findings is not generalizable to other populations and settings. The investigation revealed that guided inquiry-based learning strategy was more effective than traditional teaching method. Due to this, Chemistry teachers should use guided inquiry-based learning strategy in order to increase students' achievements, attitudes towards learning chemistry. It is more recommended that teacher should use various learning resources and teaching aids which supports hands-on activity in guided inquiry-based learning strategy that overcome students' misconceptions in chemistry. The effect of guided inquiry-based learning on different topics of chemistry in elementary school is recommended to be examined. It is also recommended to conduct a study in different settings and participants in elementary schools.

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STUDENTS' PRACTICAL PERFORMANCE-THE CASE OF PRACTICAL ORGANIC CHEMISTRY II COURSE: FLOW CHART PREPARATION

Shuma Fayera*[1] and Dereje Fedasa[1]
1. Department of Chemistry, College of Natural and Computational Science, Dambi Dollo University, Dambi Dollo, Oromia, Ethiopia
*Corresponding author e-mail: shumafayera2018@gmail.com

ABSTRACT

Practical work plays an important role in the teaching and learning of science and chemistry in particular to helping students to gain insight into scientific knowledge, skill and understandings. The research was conducted in Dambi Dollo University. To carry out the study a descriptive survey method was used. The major objective of this study was to offer an overview of the current situation in the course practical organic chemistry II of Dambi Dollo University. The sample consisted of all 20 second year second semester chemistry students, laboratory instructors and Practical Organic Chemistry II course material. The main instruments were questionnaires, content analysis of course material and observation. Qualitative and quantitative methods were employed to analyze data. The results indicated that the majority of the activities had lower inquiry level and the dominant practical work identified was demonstration activity. Laboratory instructors and students ranked the most important objective of the manual to demonstrate materials taught in lecture least. Based on these findings certain recommendations were forwarded. *[African Journal of Chemical Education—AJCE 12(2), July 2022]*

INTRODUCTION

Many students who have worked in a team in a laboratory or project-based course do not have fond memories of the experience. Some recall one or two team members doing all the work and the others simply going along for the ride but getting the same grade. Others remember dominant students, whose intense desire for a good grade led them to stifle their teammates' efforts to contribute. Still others recall arrangements in which the work was divided up and the completed parts were stapled together and turned in, with each team member knowing little or nothing about what any of the others did. Whatever else these students learned from their team experiences, they learned to avoid team projects whenever possible [1].

Laboratory activities have had a distinctive and central role in the science curriculum and science educators have suggested many benefits from engaging students in science laboratory activities [2]. According to [3], over the years, many have argued science cannot be meaningful to students without worthwhile practical laboratory experiences in laboratory. Unfortunately, the terms laboratory or practical have been used, too often without precise definition, to embrace a wide array of activities. Many arguments have been raised in the past to justify their use. But very little reason was given for their inclusion. Some laboratory activities have been designed and conducted to engage students individually, while others have sought to engage students in small groups and in large-group demonstration settings [4].

Students typically arrive at the laboratory to carry out an experiment without a very clear idea of the practical techniques they will be using, the skills they will need, or the chemistry which underlies the practical. It is usually only after the laboratory, during a write up, that students will start to work out what it was they had been doing all day. This is obviously an unsatisfactory experience and students will clearly get much more from their laboratory work if they know what they are doing beforehand. Pre-laboratory preparation is the key to achieving this and the laboratory skills philosophy has therefore been to shift the balance of work outside the laboratory to before rather than after the practical class so that students are much better informed and more confident [5]. As part of their pre-laboratory work, students are required to work through some background information about the experiment including sets of multiple choice and multiple completion tests which also provide instant feedback on any wrong answer [6]. Cooperative learning is an approach to group work that minimizes the occurrence of unpleasant situations and maximizes the learning and satisfaction that result from working on a high-performance team. A large and rapidly growing body of research confirms the effectiveness of cooperative learning in higher education [7].

Relative to students taught traditionally with instructor-centered lectures, individual assignments, and competitive grading cooperatively taught students tend to exhibit higher academic achievement, greater persistence through graduation, better high-level reasoning and critical thinking skills, deeper understanding of learned material, greater time on task and less disruptive behavior in class, lower levels of anxiety and stress, greater intrinsic motivation to learn and achieve, greater ability to view situations from others' perspectives, more positive and supportive relationships with peers, more positive attitudes toward subject areas, and higher self-esteem [8]. Another nontrivial benefit for instructors is that when assignments are done cooperatively, the number of papers to grade decreases by a factor of three or four. The proven benefits of cooperative learning notwithstanding, instructors who attempt it frequently encounter resistance and sometimes open hostility from the students. Bright students complain about begin held back by their slower teammates; weak or unassertive students complain about being discounted or ignored in group sessions; and resentments build when some team members fail to pull their weight. Knowledgeable and patient instructors find ways to deal with these problems, but others become discouraged and revert to the traditional teacher-centered instructional paradigm, which is a loss both for them and for their students [9].

The pre-laboratory instructions have been employed for physics students and cooperative learning styles and laboratory reports also applied on different disciplines. This paper describes pre-laboratory flow chart instructions, cooperative learning methods that have been proven effective in a variety of instructional settings and post laboratory report writing with presentation. We then suggested ways to maximize the benefits of the approach and to deal with the difficulties that may arise when pre-laboratory flow charts are drawn for students to have awareness on the experiments, cooperative learning methods to build a teamwork spirit of students and managing ability on practical organic chemistry II with report writing for to develop the scientific writing skills for their further career [10].

Practical works help students for the thorough understanding of the theoretical lessons that has learnt in the actual classroom. Practical works will enhance their comprehensive understanding and problem-solving skill of the subject matter although, the role of practical work as a part of science teaching and learning has varied in different countries at different periods of time [2]. Theoretical justification accompanied the inquiry approach which became dominant in science education, and field educators, for example, advocated that to develop a conceptual understanding of science; students must actively be involved in processing information [11]. Practical activities were seen as the sole means of providing this learning opportunity. The attributed outcomes of practical activities included (a) reinforcement of the understanding of scientific concepts and principles, (b) involvement in a number of handling and measuring skills and therefore promotion of the development of practical skills in students, and (c) involvement in problem solving and a "thinking style" that exposed students to the way of "working like a scientist" [6].

METHODOLOGY

The study population was Dambi Dollo University, Chemistry Department second year practical organic chemistry II class students. The study survey designed to use different assessment techniques in practical organic chemistry II laboratory class based on year two chemistry 2020 batch.

The design is intended to assess the usefulness of pre-laboratory flow charts and engaging all students in laboratory work and the effectiveness of group formation based on cooperative learning elements. In addition, this research was designed for the evaluation of post-laboratory report writing and presentation of the selected experiments as well as changing the attitude of female students for their further carrier in creating self-confident professionals of chemistry.

Sampling Techniques

All students of second year chemistry department (10 males and 10 females) in four cooperative learning groups for practical organic chemistry II were participated on this study. Students were randomly assigned to their groups.

Data Collection Instruments

The students used pre-laboratory flow charts, laboratory reports with presentation on the selected experiments, and post survey as the main instruments for collecting data. In order to gather information and facts through this instrument, check lists, criteria for report writing and presentation were prepared. Post survey questions were developed and distributed to all year two practical organic chemistry II class students.

Method of Data Analysis

Qualitative data collection techniques were used as the primary research methods. However, in order to organize, classify and analyze the gathered information, the researchers used mean, average and percentage statistics as a way to measure the students' level of improvement practical skills through the use of flow chart check lists, criteria for report writing and presentation as well as questionnaire strategies. The main sources of information were the daily observation laboratory assistances and students during the practical organic chemistry II class. The “face to face” interactions gave us the opportunity to deepen into their experiences, thoughts, and feelings.

RESULTS AND DISCUSSION

Analysis of the Objectives of the Laboratory Manual

Much discussion today surfaced concerning the need to specify goals, aims and objectives for courses in higher education, especially to laboratory teaching. The statement of aims and objectives, in any course has importance for they provide significant implication as to how the course should be planned and structured. Most agree that when planning a course, care should be taken to ensure the consistency of course aims with that of the more specific objectives and the kind of experiences provided to serve the objectives.

Comparison of the course curriculum objectives with that of the major objectives of the manual does not reveal consistency. The objective of the course for practical organic chemistry was to familiarize students with basic practical skills. This was not consistent with the objective of strengthening the theoretical part of the course, which was the objective of the manual. It does seem very important that, for practical work to be effective, the objectives should be well defined. As it is indicated in when planning a course, it is crucial to state clearly the intended objectives: what to be taught, and most importantly, what are the intended outputs of the course in a very clear way. According to undergraduate activities generally have two major purposes: they should give the student an opportunity to practice various inquiry skills, such as planning and devising an experimental program to solve problem, and an investigational work, which involves individualized problem solving, which is highly motivational especially if the student develops a sense of ownership for the problem. Through the analysis of the lesson tasks, it was discovered that the most emphasized objective of the laboratory work was as stated by the manual. Most lessons were demonstrations.

The concern of most of the laboratory lessons of the manual, as shown in table below, has been identified as the acquisition of basic organic chemistry concepts. This was manifested through a close relationship between the content of the course and the students' task in the laboratory. Such traditional view of science in school has exposed many of the students to failure and frustration. Apart from this they were identified as reasons for students' failure since they emphasized practical work as means of enhancing conceptual learning rather than acting as a source for the learning of essential skills. The most dignified aim of the course manual is to devote laboratory lessons follow closely to the theoretical part, clearly illustrate its assigned task and to make practice accommodating to theory.

Table 1: The emphasized aims in the Course Manual

No	Topics of the practical laboratory
1	**Experiment 1:** Preparation of p-Nitro aniline
2	**Experiment 2:** Acetylation of Aromatic-Amines: Preparation of Acetanilide
3	**Experiment 3:** Oxidation of Alkylarenes
4	**Experiment 4:** Azo Dyes and Ingrain Dyeing
5	**Experiment 5:**Kobel-Schmitt reaction: Preparation of β Resorcyclic Acid (2,4DihydroxybenzoicAcid)
6	**Experiment 6:** Esterification: Preparation of Amyl Acetate
8	**Experiment 7:** The Aldol Condensation and Cannizzaro Reaction
9	**Experiment 8:** Preparation of aldehydes and ketones by oxidation of alcohols
10	**Experiment 9:** Introduction to Proteins
11	**Experiment 10:** Introduction to Carbohydrates
12	**Experiment 11**: Polymers

The main aim of the course manual is to strengthen the theoretical part of the lesson.

Students' Reactions to Practical Organic Chemistry II Work

One of the questionnaires distributed among the students was lists of statements related to their experiences in Practical Organic Chemistry II laboratory activities. They were asked to what laboratory activity in Practical Organic Chemistry II.

Table 2: Mean student response to laboratory activity in Practical Organic Chemistry II

No.	Item	Mean
1	The opportunity given to plan my own experiment is very satisfying	4.80
2	Clear instructions are given about the experiment before doing the practical activities	4.80
3	Standard experiments, written up correctly, give confidence to continue with chemistry	5.00
4	Organic Chemistry laboratory should be about learning to do science through scientific investigations	4.87
5	It is always easy for me to see the point and aim of what I am doing and the importance of every laboratory activities	4.93
6	I feel most confident when the chemistry lessons were well structured and student directed	4.87
7	I appreciated the opportunity if the teacher lets me plan my own activity.	4.87

As shown in Table 2, the students responded above average and mid-point for most items which is 4.87. However, it was identified that students look difficulty to grasp the instructions of the experiment before doing the practical activities. Further it was found more satisfying and gave confidence if the lessons were well structured and student directed. On top of these most students wish organic chemistry laboratory to be a place where they could practice scientific investigations.

Students' and Instructors' Ranking of Lists of Objectives of Laboratory Activities

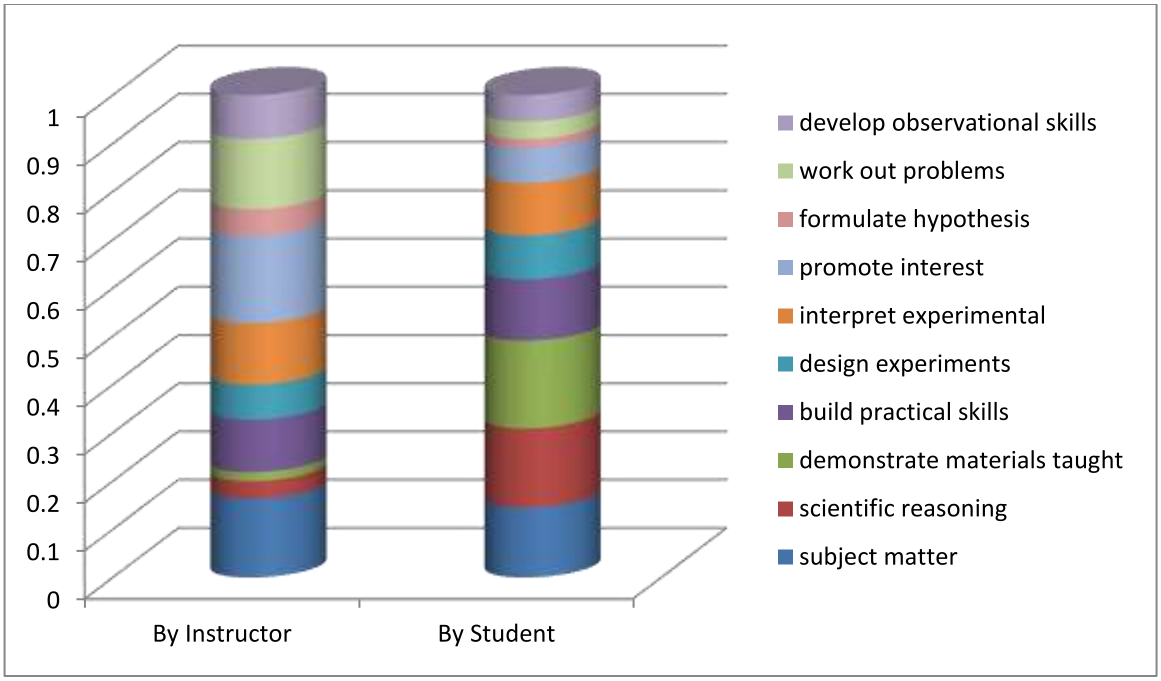
The other questionnaire distributed among students and laboratory instructors consisted of lists of aims of laboratory in science education and asked them to rank these lists of aims from the most important to the list important according to their interest. And their responses were summarized as shown in Table 3.

Table 3: Aims ranked from highest to lowest by instructors and students

N<u>o</u>	**Item**	**Rank given by most Instructors**	**Rank given by most students**
1	To improve mastery of the subject matter	Ninth	Eighth
2	To develop scientific reasoning	Second	Ninth
3	To demonstrate materials taught in lecture	First	Tenth
4	To build up practical skills	Sixth	Seventh
5	To design experiments to test hypothesis	Fourth	Fifth
6	To interpret experimental data	Seventh	Sixth
7	To promote interest in chemistry	Tenth	Fourth
8	To formulate hypothesis	Third	First
9	To work out problems	Eighth	Second
10	To introduce equipments and develop observational skills	Fifth	Thirds

The major objective of the manual, that is, to demonstrate the material thought in class (item 3), was ranked first by instructors and tenth by students. Moreover, the role of improve mastery of the subject matter (item 1) was rated low by both laboratory instructors and students.

The major objective of the manual, that is, to demonstrate the material thought in class (item 3), was ranked first by instructors and tenth by students. Moreover, the role of improve mastery of the subject matter (item 1) was rated low by both laboratory instructors and students.



SUMMARY

The major objective of this study was to offer an overview of the current situation in the course Practical Organic Chemistry II in Dambi Dollo University. All second year second semester chemistry students, laboratory instructors and Practical Organic Chemistry II course material provided data. The main instruments used were questionnaires and content analysis of the course material. Observation was also another instrument of data collection. Qualitative and quantitative methods were employed to analyze data. The data gathered from the students taking the course

Practical Organic Chemistry I through observations were analyzed qualitatively whereas the data gathered from questionnaires and content analysis were analyzed qualitatively and quantitatively.

Based on the basic research questions, the findings of this study are summarized as follows.

- The response to each question was given by the manual in almost all activities.
- Once students have the data collected, they write up formal laboratory report rather than discussing what was done. Apart from this, students were not giving due attention to the instrumentation and the way experiment is conducted.
- Most students think that the way objectives of the experiments are written is not clear to understand. Moreover, they face difficulty in understanding the importance of every laboratory activity.
- Students and instructors agreed that the most important objectives of a Chemistry laboratory work should be targeted in helping students to learn basic practical skills. Both groups ranked low the most important objective of the manual, to demonstrate materials taught in lecture.

In light of the findings and discussions made in the previous pages the following recommendations are forwarded:

- Each activity should be revised by deciding who is making the decisions: the teacher, text, or the student. There should be activities designed for goals other than teaching students' particular skills.

- Hence beside their role of strengthening the theoretical parts, other aims like to help students apply scientific reasoning, to test hypothesis, to formulate hypothesis and to work out problems should be included.

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APPENDIX

Questionnaire to be filled by second year chemistry students

Dear students,

This questioner gives you an opportunity to indicate your practical experience and reaction to the course practical organic chemistry II. Students' opinion is a valuable guide in the course planning and in evaluating the way it has been taught and the way the laboratory activities are carried out, So I kindly request you to respond to all the questions genuinely.

I appreciate your help in advance. Please write only your sex in the space provided ________

Direction I: the following are statements about what you did in your practical organic chemistry II laboratory session, you are kindly requested to rate each item on the scale shown to indicate your level of agreement. Please indicate your response by putting a tick mark in one of the boxes against each statement.

SA -Strongly agree, **A** -Agree, **UD** -Undecided, **DA** -Disagree and **SD** –Strongly disagree.

No.	**Item**	**SA**	**A**	**UD**	**DA**	**SD**
1	The opportunity given to plan my own experiment is very satisfying					
2	Clear instructions are given about the experiment before doing the practical activities					
3	Standard experiments, written up correctly, give confidence to continue with chemistry					
4	Organic Chemistry laboratory should be about learning to do science through scientific investigations					
5	It is always easy for me to see the point and aim of what I am doing and the importance of every laboratory activity					
6	I feel most confident when the chemistry lessons were well structured, and student directed					
7	I appreciated the opportunity if the teacher lets me plan my own activity.					

Direction II; the following are lists of aims for laboratory activities in science education; you are kindly requested to rank this list of aims from the most important to the least important.

No	Item	Rank
1	To improve mastery of the subject matter	
2	To develop scientific reasoning	
3	To demonstrate materials taught in lecture	
4	To build up practical skills	
5	To design experiments to test hypothesis	
6	To interpret experimental data	
7	To promote interest in chemistry	
8	To formulate hypothesis	
9	To work out problems	
10	To introduce equipments and develop observational skills	

HIGH SCHOOL STUDENTS' LEARNING DIFFICULTIES IN ELECTROCHEMISTRY: A MINI—REVIEW

Mirtachew Tihar Ali*, Abebe Reda Woldu, Asfaw Geremew Yohannes
Department of Teacher Education, Norwegian University of Science and Technology, NTNU, Norway
*Corresponding author email: mirtachew.t.ali@ntnu.no

ABSTRACT

In this manuscript, we reviewed over 60 reports on the learning difficulties of electrochemistry in high-school education. In the first part of the review, we intend to introduce the learning difficulties that typically hamper in learning electrochemistry. Second, are those intending to introduce the apparent students' misconceptions in electrochemistry. Thirdly, the remedies that would improve the teaching-learning process of electrochemistry are highlighted. In order to attain this, the Web of Science search index was utilized to find out articles describing electrochemistry, learning difficulty, misconception, laboratory instruction, history, and philosophy of science terms (and phrases). The results revealed that there are over fifty most common students' misconceptions pertaining to the selected electrochemistry topics. Students' lack of ability to integrate big or core ideas with structure-property relationships; absence of teaching aids; misinterpretations of language in scientific contexts; frequent overloading of students' working memory; inability to represent chemical phenomena at the macroscopic, particulate, and symbolic levels; and teachers' and textbooks' made misconceptions are the main challenges that contribute to the students' learning difficulties in electrochemistry. As remedies, this paper identified the infusion of teaching methods such as laboratory-based instruction, the infusion of history, and philosophy of science in the electrochemistry lessons. Such teaching methods not just enhance the comprehension of electrochemistry concepts, but also improve students' attitudes towards the topic. The implications of the study to teachers and curriculum writers are discussed. *[African Journal of Chemical Education—AJCE 12(2), July 2022]*

INTRODUCTION

The history of electrochemistry is full of adventure and has played crucial role in advancing the understanding of chemistry and technology that shaped the production of industry and daily life in the 21st century. Alessandro Volta's invention of the first modern electrical battery in 1800—voltaic pile used to split water into hydrogen and oxygen in a process called electrolysis [1] is a cornerstone for the flourishment of electrochemistry. Little by little, many electrochemical concepts have been introduced in school chemistry curricula and many metals, such as Na, K, Al etc, were extracted from their compounds through electrolysis [2]. The ubiquitous nature of batteries in our day-to-day usage and the application of electrolysis for understanding corrosion, electroplating and extraction of metals lends electrochemistry to be widely studied at all levels of education elsewhere.

Fundamental topics of electrochemistry such as electrolytes, ions, electrolytic conduction, oxidation-reduction reactions, and electrochemical cells are introduced in secondary education [2-4]. However, electrochemistry is reported to be one of the difficult topics to both teachers and students (e.g. [3, 5-8, 9]. Some of the students' problems associated with learning electrochemistry topics are: (i) they get confused between the flow of electrons in metallic conductors and in the electrolytes; (ii) they cannot identify anode and cathode/negative and positive poles in the cell; (iii) their inability to explain the process happening at the anode and cathode; (iv) mixing up the oxidation and reduction processes that occur at the electrodes, and (v) they have difficulty in understanding an electrolyte concept [6]. Difficulties and misconceptions in electrochemistry is not only limited to students but also pre-service and in-service high school teachers [7-9]. To the best of our knowledge, review articles on the practices of teaching-learning of electrochemistry in lower and senior high-school levels are scant [3-4, 10].

This review is aimed at presenting the students' learning difficulties and possible remedies associated with teaching and learning of electrochemistry in high schools elsewhere. For this purpose two research questions had been set. These are:

1. What are the students' learning difficulties of electrochemistry in high schools?
2. How do students' learning difficulties related to electrochemistry are remedied in high-school classrooms?

METHODS

In the first part of this article, we aim to summarize reports that describe high-school students' learning difficulties of electrochemistry. In order to attain this, the Web of Science search index was used to source articles describing electrochemistry, misconceptions, learning difficulty, laboratory instruction, history, and philosophy of science terms (and phrases). Results obtained were filtered initially for high-school electrochemistry lesson, and then upon reading, filtered again to remove those that did not relate to high-school level electrochemistry topics. Cited and citing references of these articles were consulted to identify additional relevant material. Given the very extensive nature of literature on electrochemistry education, we do not consider having captured all of the reports on electrochemistry, but do consider that we have captured a suitable sample size to derive the evidence for the students' learning difficulties and the potential remedies. It is worth stating that while interesting literature on electrochemistry education relevant to modern teaching extends back to at least the 1800s; our survey starts in the early 1990s, as different teaching strategies emerged that made alternatives to better learn electrochemistry. In addition, where possible, we identified the type of electrochemistry topics (oxidation-reduction, galvanic, and electrolytic cells) and state that wherever possible when summarizing a report.

PART 1: A REVIEW OF LEARNING DIFFICULTIES

1.1. Learning difficulties in electrochemistry

Electrochemistry teaching and learning is one of the difficult lessons in high school chemistry and tertiary education elsewhere. Many chemical educators reported learning difficulties in understanding electrochemistry concepts which are prevalent in Africa [11]; Asia [5, 13, 14-15]; Europe [4, 16]; Australia [17]; and United States of America [18]. For instance, high school students, and teachers, come across problems in comprehending electric current, oxidation-reduction, electrolytes, galvanic cell [20] and electrolysis [7, 17, 19-20]. Students' limitations in understanding the 'particulate nature of matter' are reckoned the root cause for the challenges in learning chemistry concepts in general and electrochemistry in particular [21-22].. Thus, visual (what can be seen, touched and smell); sub-microscopic (atoms, molecules, ions and structures), and symbolic (representations of formulae, equations, mathematical expressions and graphs) should be employed for effective chemistry teaching [23-24]. In addition, students' limited knowledge of core or big ideas (e.g. see [25-26] in chemistry also creates difficulty to give scientific explanation and describe structure—property relationships [27-28].

[11] Reported the effect of using teaching models to minimize the known misconceptions in electrochemistry at South African university students. Their results revealed that students showed an improvement in understanding electrochemical cells at microscopic level along with the reduction of students' misconceptions. But students were found to entertain some of the misconceptions, after completing the lesson, such as: "current is a flow of electrons"; "ions will be able to conduct the electrons and complete the circuit"; "potassium sulphate has delocalized electrons and positive protons that move to the opposite electrodes when a current is applied"; and "anions produce electrons which conduct [electricity]" (p.107). Similar results were found in studies that take place at American students [18] and Australian students [17].

[5] Investigated Pakistani high school students' conceptual difficulties in the areas of redox reactions, galvanic and electrolytic cells. The results of their study suggested that students' correct response was only 67% of the concept-based test. The main factors that caused conceptual difficulties in comprehension were: (i) poor background knowledge, (ii) absence of teaching aids, and (iii) misinterpretation of everyday language into chemistry.

[12] Investigated high school students' (grade10-12) conceptual understanding of electrolyte concept in China. These authors found out that students faced difficulty in earning deep knowledge of electrolyte. [12] Studied 559 grade 10 to 12 students' conceptual understanding of electrolyte by using Rasch measurement instrument, which serve to measure both summative and diagnostic assessments of misconceptions in electrolyte concepts at two cities of China. The results indicated that students' conceptual understanding was enhanced with increasing grade levels while each of the different grade levels were found to hold misconceptions. [12] Reported the 10^{th} grade students' understanding of the concept of *electrolyte* in China high school using a phenomenography method by interviewing eight students to qualitatively assess their level of understanding. Their research findings revealed that electrolyte concept was found to be difficult to be understood by students.

[13, 15] examined Malaysian high school students' conceptual understanding of electrolysis. In a study of 330 Malaysian high school students, [13] reported a two-tier 17 item multiple choice Electrolysis Diagnostic Instrument (EDI) to investigate students' understanding of basic electrolysis concept. She identified more than twenty misconceptions pertaining to different electrolysis concepts such as: (i) the nature and reaction of the electrodes; (ii) the migration of ions; (iii) the preferential discharge of ions; (iv) the products of electrolysis; and (v) changes in the concentration and color of the electrolyte. According to [15] high school students in Malaysia face difficulties in explaining basic electrolysis concepts and lacking confidence in correctly answering test questions. They recommended that teachers "should help select the teaching materials such as

the appropriate use of models, illustrations and definitions of new terminology to help students learn chemistry concepts more effectively" (p.1341).

[14] Investigated 244 Indonesian and 189 Japanese public senior high school students' conception of electrochemical concepts (e.g. electrolysis, electricity flow, the voltaic cell and the electrode reactions). The result revealed that both samples exhibited difficulty in understanding of the concepts and held misconceptions.

A related study in German upper secondary schools investigated the learning difficulty of students [16]. The study focused on four areas, namely, electrolytes; transport of electric charges in electrolyte solutions; the anode and the cathode; and the minus and plus poles. Students' reasoning was based on the misconceptions: "the electric current produces ions"; "electrons migrate through the solution from one electrode to the other"; "the cathode is always the minus pole, the anode the plus pole" and "the plus and minus poles carries charges" [16].

Student teachers showed teaching difficulty of electrolysis whereby they were unable to explain what an electrolysis is and why the electrochemical phenomena in electrolysis process has happened as well as they did not ponder the actual electrolysis mechanisms to their students [7]. Their results revealed that only two students were able to explain electrolysis as a process where an electric current drives the reaction to a non-spontaneous direction. Some student teachers also hold misconceptions in electrolysis. All the aforementioned difficulties and misconceptions related to students and teachers, necessitates remedies that could led to an effective classroom discourse and robust understanding of electrochemistry.

PART 2: MISCONCEPTIONS IN ELECTROCHEMISTRY

Misconception is referred to as learners' scientific views and beliefs that are inconsistent with the commonly accepted views of the scientific community [8, 29-31].Science educators also coined various terms for misconceptions such as alternative conceptions [10], children's science [30-31], alternative frameworks [12, 17], and conceptual or propositional knowledge [29] to describe students' understanding that is in conflict with the scientific view. An awareness of the misconceptions in electrochemistry would guide high-school teachers, textbook writers, curriculum developers and policy makers so as to design and execute an effective instruction, assessment and implementation of a curriculum so that students' scientific conception would be in harmony with the consensus of the scientific community.

As Piaget (Cited in [26], p.6059) contended, when there is inconsistency in the understanding of a new concept and our pre-existing knowledge, the conceptual schema of the learner tends to modify in a way that fits the 'new sensory data'. Thus, the students can have different views on a particular concept to accept it as correct or incorrect since they are in a position to compile and integrate knowledge under a constructivist paradigm. The chance of creating their own wildly accepted perspectives to understand chemical phenomena is the cause for holding misconceptions

[26]. The misconceptions research in electrochemistry is well documented in various studies [8, 14-16, 18, 21, 32-37]. However, several chemical educators strongly criticized that many misconception research has paid little attention on the possible sources of the learning difficulties and misconceptions. [38, p.230] clearly argued that "Chemistry educators who strongly emphasized that developing effective instructional approaches to overcome misconceptions requires identifying and considering the underlying sources of these misconceptions, rather than merely listing them.

Creative exercises that promote meaningful conceptual links between prior knowledge and new knowledge, pretest and posttest exams, and interviews and students' reflection about their own learning and small group discussions are used to trace misconceptions held by students in electrochemistry. Integrated concept mapping and visual animation is also important in identifying students' misconceptions and attracting their interest and enhancing the performance of learning in electrochemistry [39]. The possible origins of misconceptions are: (1) inadequate prerequisite knowledge; (2) frequent overloading of students' working memory; inability to think about the same chemical processes at the macroscopic, particulate and symbolic levels; misinterpretation of everyday language in chemical contexts; (3) the use of concepts and algorithms in a rote fashion without any attempt to understand fully and analyze the problem; (4) Teachers and textbook-derived misconceptions ; and (5) the format and order used in chemistry textbooks [3, 18, 29, 40]. These learning difficulties and misconceptions necessitate an effective instructional approaches and strategies such as conceptual change approach [33, 41].

Conceptual change instruction is referred to as a teaching method that requires restructuring of learners' existing conceptual frameworks to a much more organized scientific knowledge structure [30]. It should create opportunity for learners' dissatisfaction with their misconceptions and the new conception should be intelligible (understandable), plausible (believable) and fruitful (worthwhile) so as to extinguish their misconceptions and for a sound understanding to occur [10, 42]. The strategies that are very helpful for cognitive restructuring to be feasible includes: providing opportunities to exchange ideas in the classroom and encouraging group discussions, eliciting students' experiences, guiding students to reflect their own learning and giving freedom to take responsibility to their own learning as well as make meaning to their experiences [10, 30]. However, students' misconceptions in electrochemistry could not be fully avoided due to its nature of resistance to change [31]. While students' active engagement in scientific activities is a prerequisite for cognitive restructuring to occur, learning science involves a complex interplay between personal experience, language, and socialization.

Previously, the conceptual understanding of high school students (grades 9-12) has been studied and an overwhelming number of misconceptions on oxidation-reduction and electrochemistry were identified [4, 6, 10, 14, 16, 20, 31, 35, 42-46]. The most common misconceptions on oxidation-reduction and electrochemistry were grouped into five subcategories: (1) Electric circuits; (2) Oxidation-Reduction; (3) Galvanic/Electrochemical cells; (4) Electrolytic cells, and (5) Electrolytes are indicated in Table 1-5 below.

2.1 Electric circuits

The use of different conventions to explain electric current, "flow of electrons" model and "flow of electric charges" model in chemistry and physics subjects respectively, leads students to misinterpret electric current as it is generated by the movement of (only) electrons in chemistry and the flow of positive charges in physics subjects, as indicated in conceptions 1, 4, 5, 8 and 9 in Table 1. Actually, the two models were used to describe electric current, and electricity in general, contains similar concepts—the flow of electrons constitute current in chemistry and the flow of electric charges which is basically the electrons that have negative charges in physics. Due to the students' application of different models, students compartmentalized chemistry and physics and view these subjects as unrelated and different disciplines.

Teachers must show the interrelatedness of the electricity concepts in chemistry and physics and the importance of the flow of positive and negative ions or charges (in solutions) and electrons (in the external wire and in metallic conductors) in generating electric current should be given witty explanations to the students. However, a simplified use of "flow of charge" model has limitations to fully explain the metallic conduction process.

Table 1 Misconception in Electric Circuits

Electric circuits
1. Electric current only occurs by movement of electrons
2. Electrons enter the electrolyte at the cathode, move through the electrolyte and emerge at the anode to complete the circuit
3. The salt bridge supplies the electrons to complete the circuit and assists the flow of current (electrons) because positive ions in the bridge attract electrons from one half-cell to another
4. Only negatively charged ions constitutes the flow of current in the electrolyte and the salt bridge
5. Protons and electrons flow in an opposite direction to constitute an electric current
6. Electrons can flow through aqueous solutions without assistance from the ions
7. Electrons move in solution by being "carried" by the ion
8. Protons flow in metallic conductors
9. Electricity in chemistry and physics is different because the current flows in opposite directions
10. The current flows because there is a difference in charge at the anode and cathode.

In conceptions 2, 3, and 6, students misinterpret the statement "the salt bridge serves to "complete" the circuit, allowing electrical current to flow" as if electrons pass through the salt bridge and solution in order for the cell to generate constant electricity. The effects of language barrier, everyday language with dual meanings, in scientific contexts hinder students' chemistry learning in such a way that the most frequently used meaning persists. The teacher should scaffold students' developing competence to interrelate the macroscopic, sub-microscopic and symbolic representations of chemical concepts and this is an effective instructional strategy to extinguish misconceptions and for successful learning to occur [24, 47-48]. Similarly, the use of the statement "positive and negative ions carry charges" or "ions are charge carriers" confuses students' as the everyday language "carry" gives opportunity to devise their own way to understand electrons could be carried by the ions and flows in either direction into the electrodes, conception 7. Thus, teachers and textbook writers should carefully consider the language barrier in chemistry learning and be explicit in defining chemical concepts. Students' lack of understanding of the relative tendency of electrodes to undergo oxidation and reduction, leads to believe that the difference in charges between the electrodes is the driving force for an electric current to flow in the external wire, conception 10.

2.2 Oxidation-reduction

The use of multiple models to define oxidation and reduction processes: addition of oxygen or removal of oxygen; addition of hydrogen or removal of hydrogen; transfer of electrons from one substance to another, and the change in oxidation state is misleading and confusing [3, 10]. For example, in a combustion reaction $C+O_2 \rightarrow CO_2$, students regard this process only as an oxidation reaction since oxygen has been added, conception 17. When students use the oxygen addition or removal and hydrogen addition or removal models and as such try to apply it for all chemical equations, they will fail to identify the oxidation and reduction half-cells and the chemical changes that occur due to these changes, conceptions 11, 18 and 19.

Teachers should be consistent with their models while defining oxidation and reduction concepts and should encourage students to use the ‘change in oxidation state model which is more realistic to define all redox equations certainly [49].

Table 2 Misconceptions in Oxidation-Reduction

Oxidation-reduction
11. Metal rods only act as an electron carrier during redox reactions and there will be no change in the electrodes physical structure
12. Inert electrodes can be oxidized or reduced
13. The oxidation state of an element is the same as the charge of the monatomic ion of that element
14. Oxidation states or numbers can be assigned to polyatomic molecules and/or polyatomic ions
15. The charge of a polyatomic species indicates the oxidation states of the molecule or ion
16. In an equation, changes in the charges of the polyatomic species can be used to determine the numbers of electrons removed from, or gained by, reacting species
17. Oxidation and reduction processes can occur independently
18. When electrons are transferred from copper to silver, the charges of these species do not change
19. In all chemical equations the “addition” and ”removal” of oxygen and hydrogen can be used to identify oxidation and reduction
20. No reaction will occur in inert electrodes

While assigning the oxidation states of a substance is important in the identification of oxidation and reduction reactions, students’ have difficulty in giving correct oxidation states for an element and polyatomic ions—assigning an oxidation state of +2 for Zn metal and in $Cr_2O_7^{2-}$ ion they assign an oxidation state of -2 for Cr but in reality, it is +6. This is indicated in students' conceptions 13 and 15. They wrongly thought that the oxidation state of polyatomic molecules or ions can be assigned, conception 14 and is the same as its charge, conception15. In a chemical equation that contains CO_3^{2-} ion in the reactant side and CO_2 in the product side, students assign an oxidation state of -2 for CO_3^{2-} and 0 to CO_2 molecule and thought the process is an oxidation reaction because the oxidation state has changed from -2 to 0, conceptions 14, 15 and 16.

In conceptions 12 and 20, students literally translate the word "inert" as it means one that does not react. However, inert electrodes conduct electricity and reaction can occur at this electrode even though the inert electrode itself does not react. The everyday language in chemical context misled students to think either inert electrodes could be reduced and oxidized, or they will not react at all. Teachers and textbook writers should critically select an appropriate word that does not confuse students' thinking towards chemistry learning.

2.3 Galvanic/Electrochemical cells

Labeling anode and cathode as negative and positive charges exacerbates students' understanding on the mechanism of electron flow along the external wire and the transport of anions and cations into the electrolyte solutions and salt bridge. Students who hold a common belief that anode is negatively charged (with surplus electrons) could not explain how a drift of anions come to the negatively charged anode electrode, conception 21. In the same vein, students who believe that anode is a positively charged species were unable to explain the flow of electrons from the anode to the cathode (with electron deficiency) to undergo a reduction reaction, conception 22.

Students showed lack of understanding about the functions of the salt bridge in electrochemical cells, conceptions 23, 33, 35 and 38. The statements used to indicated the role of salt bridge "the salt bridge complete the circuit, allowing the electrical current to flow" and electrolytes and salt bridge serve to "maintain the electrical neutrality of the circuit" are misunderstood by the students and believe that the salt bridge is helpful to transport both positively charged and negatively charged ions as well as electrons from one electrode to the other so that the development of positive and negative charges at the electrodes will be restricted. The common words "complete" and "neutral" are misrepresented in the scientific context and due to this language barrier, students could not understand what the actual function of salt bridge is.

Table 3 Misconceptions in Galvanic/Electrochemical cells

Galvanic/Electrochemical cells
21. The anode is a negative electrode and because of this it attracts cations and the cathode is positively charged and because of this it attracts anions
22. The anode is positively charged because it has lost electrons while the cathode is negatively charged because it has gained electrons
23. No transfer of salt-generated ions from one to the other cell
24. The identity of anode and cathode depends on the physical placement of the half-cells
25. In an electrochemical cells oxidation occurs at anode and reduction occurs at the cathode, while in electrolytic cells oxidation occurs at the cathode and reduction occurs at the anode

26. No reactions will occur if inert electrodes are used
27. In electrochemical cells, as the attraction forces between anions and cations affects ions velocity to electrodes, different potentials are read when different solutions are used in the cells
28. Protons and electrons flowing in opposite directions cause a potential difference between the two ends of the wire
29. There is high electron concentration at the anode
30. In standard reduction potential tables the species with the highest E^o value is the anode
31. The number of neutral atoms increases in the anode, while it decreases in the cathode
32. The number of metal cations increases in the reduction half cell, while it decreases in the oxidation half cell
33. Salt-generated cations transferred from the reduction to the oxidation half cell
34. The anions and cations move until their concentrations in both half-cells are equal.
35. Cations in the salt bridge and the electrolyte accept electrons and transfer them from the cathode to the anode.
36. The cathode is always the minus pole, the anode the plus pole
37. The anode electrode mass increases over time
38. The positively charged ions migrate toward the anode electrode, whereas the negatively charged ions migrate towards the cathode electrode over the salt bridge.

In order to minimize this confusion, simple paper-based and low-cost galvanic cells are very helpful [50-53]. This is since “the models of galvanic cells provided students a chance to access the microscopic level to direct perception” [20, p.403].

Some students have difficulty in identifying the anode and cathode electrodes, conceptions 24 and 36. Labeling of anode and cathode electrodes as either negative and positive is highly dependent on the relative tendency of the electrodes to lose or gain electrons but this does not necessarily mean that the electrodes possess absolute negative or positive charges. Thus, the identification of anode and cathode has nothing to do with their physical placement, even though some students believe it so, conception 24. The assignment of positive and negative charge to the anode and cathode is dependent on the type of cell, whether galvanic or electrolytic cell, since in galvanic cells the lost electrons in the anode did not need any additional electrical energy to transport them to the cathode but in electrolytic cell, a direct current is needed to transport the lost electrons in the anode and thus the anode should be connected to the positive terminal of the battery.

Lack of this basic understanding of labeling anode and cathode as either positive or negative, creates confusion among some students to have conception that anode is always a negative pole while cathode is positive pole, conception 36. Most students' inability to distinguish between electrochemical and electrolytic cells, creates learning difficulties in understanding the redox reactions that occur at these cells. Furthermore, teachers often used the word "reversed" to describe the processes in electrolytic cells compared to galvanic cell. This led students to a wrong conception that oxidation occurs at the cathode while reduction occurs at the anode in electrolytic cell, conception 25. Teachers need to critically scrutinize what appropriate words, that did not interfere in students' chemistry learning, should be used in order to describe electrochemical and electrolytic cell concepts. Another interesting common belief of students on the function of inert electrodes is that no reaction will occur at inert electrodes, conception 26. Misinterpretation of the word "inert" in their everyday language prevents students to think that there is a reaction in the inert electrodes even though they did not participate in the reaction. Still teachers should be careful in using everyday languages in the scientific contexts in chemistry teaching.

Some students believed that the type of solutions used in galvanic cell affects the amount of cell potential generated due to redox reactions, conception 27. As long as the solutions used in the electrodes did not interfere in the redox reactions, every galvanic cell has a characteristic cell voltage irrespective of the types of solutions with known concentrations are used. This is students' naïve belief that should be corrected by engaging students in group discussions that promote critical thinking skills.

Students' Conception 28 arises from the compartmentalization of knowledge in chemistry and physics. (See conception 5 above).

Some students have difficulties in understanding how galvanic cell performs and they happened to misrepresent the concept of electrical neutrality in a cell, conceptions 29, 31, 32, and 34. In order to remedy these conceptions, teachers should use small-scale experiments along with model kits via inquiry-based laboratory instruction that could activate students' cognition and attract their interest to learn galvanic cells in a particulate level effectively [20].

Conception 30 is erroneous information that is held by students through mere rote memorization for the purpose of passing exams instead of making meaning to it. [10] Described such kinds of learning as “the information is neither meaningful nor understandable to the student and has been rote learned in order to answer test questions” (p.86).

Students who lack the ability to understand the phenomena at a particulate/microscopic level showed a weak understanding in describing what is happening in the amount of mass changes in electrodes of a galvanic cell, conception 37.

The use of computer animations and animated concept mapping [39], small scale experiments that encourages students’ visualization ability [20, 50-53], and chemistry triplet learning [24, 40-48] are very helpful for creating sound understanding of electrochemical concepts at the particulate, visual and symbolic levels.

2.4. Electrolytic cells

Students’ inability to explain the electrolytic process as a process that consumes electrical energy to effect a chemical change led students to hold a number of misconceptions such as the oxidation and reduction half-cell reactions will not be affected when the applied voltage is attached at either side of the electrodes, conceptions 39, 43 & 44.

Table 4 Misconceptions in Electrolytic Cells

Electrolytic cells
39. In electrolytic cells the polarity of the terminals of the applied voltage has no effect on the site of the anode and cathode
40. Water does not react during the electrolysis of an aqueous solution
41. The same products are produced in both aqueous and molten situations of salt electrolysis
42. There is no association between the calculated e.m.f of an electrolytic cell and the magnitude of the applied voltage
43. In electrolytic cells with identical electrodes connected to the battery the same reactions will occur at each electrode
44. It is not important which sides of the battery are connected to the electrodes as the same reactions occur at the electrodes
45. The predicted e.m.f. for an electrolytic cell may be positive
46. Electrolytes are decomposed by electric current.
47. No electrolytic anions transfer from one to the other half-cell
48. No reactions will occur at the surface of inert electrodes
49. Processes in electrolytic cells are the reverse of those in electrochemical cells

The students' common belief that the site of the applied voltage does not affect the redox process arouse from the confusion between the chemical changes of anode and cathode electrodes and due to the limitation in understanding the mechanism of the flow of electrons in the external wire and the transport of charges into the electrolyte solution. Since electrolytic process is a non-spontaneous process, the anode should be connected to the positive terminal of the battery so that the lost electrons in the anode electrode will be transported to the cathode electrode, which is connected to the negative terminal of the applied voltage or battery, through the external wire. However, the change in the site of connection of the electrodes with the battery will also change the types of products obtained at each electrode. This problem can be remedied by making use of small-scale electrolysis experiments as they could give opportunity for students to realize what is happening at microscopic, particulate, or sub-microscopic and symbolic levels [55-57]. In addition, small group discussions among students will enhance their understanding about the electrolytic concepts and the principles associated with it. Conception 45 relate to the confusion of the principles of electrolytic cell. Since the function of the electrolytic process is not to generate electricity, the e.m.f. value will not be positive as the process is non-spontaneous—it would rather need an external direct current source to effect the chemical change.

Students' inability to describe an oxidation-reduction reaction led them to think that the applied voltage that is needed to drive a redox reaction in electrolytic cell is independent of the calculated cell potential, conception 42. The voltage required to cause electrolysis depends on the specific half-reactions, i.e. the applied voltage should be greater than the calculated e.m.f in order to force the electrons to flow in the opposite direction. This is similar to conceptions 39 and 44.

Conceptions 40 and 41 relates to the lack of understanding of the discharging and oxidation and reduction processes of the molecules and ions. The reason for students' misconception might be associated with their incapability to provide the dissolution equation of salt in water and inability to understand the ions present in the molten salt. Another reason might be the lack of understanding of the selective discharging of the ions/or molecules at either of the electrodes. In electrolysis of water in aqueous solution, the metal cations of the salt will not be discharged as water molecules require lower voltage to do so.

Students' naïve belief that an electric current helps to decompose the ions in an electrolyte solution, conception 46, arouse from misinterpretation of electrolysis process as the decomposing ions in the electrolyte instead of the splitting of a compound into its corresponding elements.

Conception 47 relates the poor understanding of the flow current in an electrolytic cell. Some students believe that in electrolytes electrons are carried by the ions and moved to the electrodes while other students do not think anions will be transferred from one to another cell. This misconception is due to incapability to explain how electrical neutrality of a cell is maintained.

The functions of inert electrodes create some sort of confusion to some students, conception 48, and take the literal meaning of "inert" as it does not react. The difference between electrochemical and electrolytic cells is misunderstood by students, conception 49. Teachers and textbooks' statements "electrolytic cell processes are the reverse of electrochemical processes" is misunderstood by students as each and every process of the electrolytic cell is the direct opposite of electrochemical cells. Simply taking the common meaning "reverse" in everyday language, some students believed that oxidation occurs at the cathode while reduction occurs at the anode in electrolytic cells. Another student might believe that before writing a net cell reaction, the half-cell reaction equations must be exchanged, etc.

2.5. Electrolytes

Conceptions 50 and 51 indicates students' lack of understanding of the electric current flow model in chemistry and physics—compartmentalization of knowledge. Some students' thought that strong ionic boding occurs in solutions, conceptions 52, 53 and 54. Other students have difficulty in distinguishing between ionization and dissolution processes, conception 55.

Table 5 Misconceptions in Electrolytes

Electrolytes
50. Protons flow in electrolytes (regardless of whether the solution is acidic, basic or neutral)
51. Protons and electrons flow in opposite directions in an electrolyte
52. Aqueous solution contains sodium chloride molecules, in which sodium and chlorine molecules are bound together in 1:1 proportion
53. Cations and anions are attached or bonded together as ion pairs in water
54. Ionization and dissolution are the same process
55. Electrolyte solution are not conductive

PART 3: STRATEGIES FOR EFFECTIVE ELECTROCHEMISTRY LEARNING

3.1. Laboratory instruction for teaching and learning electrochemistry

Table 6 shows a summary of laboratory instruction approaches and strategies on effective electrochemistry teaching and learning at high school level. In a recent review study, [4] investigated high school and university students' learning challenges and effective teaching strategies and approaches intended for enhancing conceptual understanding and increasing positive attitudes towards electrochemistry. The results revealed that inquiry-based 5E instruction model and projected-based learning activities indicated a profound impact in: (i) the comprehension of electrochemistry concepts, (ii) for holding positive attitudes in chemistry learning and (iii) development of communication skills. This is consistent with [67] commentary paper on his 32 years' experience in using laboratory instruction for teaching chemistry. During his 2010 ACS "Award for Achievement in Research for the Teaching and Learning of Chemistry", he explicitly addressed the impacts of inquiry-based laboratory teaching as an effective instruction for students' conceptual understanding and increasing their attitudes. [59] Investigated the effect of five inquiry-based laboratory activities aimed at improving 62 Turkish high school students' achievement and positive attitudes in electrochemistry learning.

Their findings strongly suggested that inquiry-based instruction has greatly supported students' comprehension of electrochemistry concepts on: (1) flow of electrons, (2) function of salt bridge, (3) identification of anode and cathode and (4) earning deep and robust understanding of electrochemical cells. In addition, students were found to hold positive attitude towards chemistry and laboratory work. Several similar studies have also been reported on the merits of inquiry-based laboratory instruction [20, 59-54].

A study which is conducted on 50 form four (equivalent to grade 9) high school students in Malaysia assessed the effectiveness of integrated STEM lab-activities in facilitating students' understanding of electrolysis using two-tier 17-items Electrolysis Diagnostic Instrument (EDI) and interviewing students [67]. These researchers found out that students' understanding of electrolysis has been improved with 33.6% of the variance in the pre-and post-test explained by the treatment.

Several small-scale and low-cost experiments for successful teachings of electrolysis to high school students are well established [54-57] While small-scale and low-cost electrochemistry experiments are important in minimizing students' conceptual difficulties, yet the use of molecular animations and inexpensive, portable, reproducible, and flexible model kits via 5E inquiry learning approach has synergetic effect that leads to an effective electrochemistry instruction [20].

Some studies are reported on paper-based galvanic cells which have high impact in teaching electrochemistry in high school [50-53].

Table 6 Summary of Laboratory Instruction Strategies and Proposals for Effective Teaching and Learning in Electrochemistry at High Schools

Main Features	Author (s) and Year of Publication
A Small-Scale and Low-Cost Apparatus for the Electrolysis of water	[54]
Small-Scale and Low-Cost Galvanic Cells	[64]
A Model Approach to the Electrochemical Cell: An Inquiry Activity	[40]

Hydrogen and fuel cell educational activities in Turkey	[65]
Microscale Electrolysis Using Coin-Type Lithium Batteries and Filter Paper	[55]
Electrolysis of Water in the Secondary School Science Laboratory with Inexpensive Microfluidics	[56]
Grade 12 students' conceptual understanding and mental models of galvanic cells before and after learning by using small-scale experiments in conjunction with a model kit	[20]
An Easy-To-Assemble Three-Part Galvanic Cell	[52]
A microfluidic galvanic cell on a single layer of paper	[53]
STEM teaching in a chemistry laboratory “How to build a simple battery in the laboratory”	[66]
Electrochemistry with Simple Materials to Create Designs and Write Messages	[57]
Teaching and Learning Electrochemistry	[4]
Integrated STEM-lab activities in improving secondary school Students' understanding of electrolysis	[67]

3.2. History and philosophy of science

The use of historical perspectives of science as instructional method for teaching introductory high school chemistry courses are reported by many chemistry educators [1, 48, 68-72].

[25] Pointed that history of science "helps to recognize struggles in the understanding of central concepts and big ideas in the discipline, many of them similar to the challenges that students face in our classrooms" (p.837). Replication of 19th century electrochemistry experiments such as Alessandro Volta's battery and reconstructing it played crucial role to recover knowledge and to advance electrochemistry knowledge in the current science education [1]. Chang concluded that historical experiments, complementary experiments, are very intriguing for students and teachers to develop 'a genuine experience of open-ended scientific inquiry' and learn the essence of original research work by reconstructing earlier experiments (p.337). [70] reported reconstructing of an iconic experiment on electrolysis of water to teach pre-service teachers in a history of science course at Norwegian University of Science and Technology in Norway using water-splitting apparatus and voltaic pile— which are part of historical collections of the university. Water-splitting apparatus and voltaic pile are featured in the 19th and 20th century physics and chemistry textbooks and high school teaching classrooms. Authors built a replica of voltaic pile. Results of these authors showed that students appreciated the electrochemistry experiment. But authors also found a peculiar result about the ratio of hydrogen to oxygen which was not exactly 2:1 as suggested in written sources even though authors enjoyed their experience a lot.

It seems apparent that historical experiments are very helpful to the understanding of scientific concepts as students and teachers will get opportunities to ask critical questions such as: Why do we believe what scientists said then? Why is it happened so? What are the reasons for such findings? [25] Contended that historical perspective of science teaching aids to open our eyes to “the underlying themes, essential questions, scales of analysis, conceptual dimensions, contextual issues, and philosophical considerations that have emerged from the work of chemists throughout the ages”.

[72] Investigated grade 11 high school students’ conceptual mastery of energy in physics course by making use of HPS. Researchers designed a teaching strategy based on HPS approach using five teaching activities: (i) study and reproduction of Joule's paddle-wheel experiment, (ii) introduction of Rankine's definition, (iii) study of a historical text of Joule, (iv) use of an “ID card of energy,” and (v) early introduction and multiple application of the principle of energy conservation. The results showed that the teaching design is promising, and students’ conceptual comprehension of energy is enhanced. Electrochemistry teaching can also be adapted using this pedagogy as it deals with the electrochemical transformation of energy but with a different teaching context.

Some researchers reported the impact of incorporation of historical experiments in high school chemistry textbooks’ for effective chemistry teaching [68-69] In his study, Lin suggested that textbooks should emphasize students’ qualitative conceptual understanding of chemistry concepts than algorithmic mathematical problems, as students can solve it correctly but with little understanding of concepts [68]. His findings indicated that experimental students were able to comprehend “atmospheric pressure” and “atoms” along with minimizing misconceptions. He recommended that “debating” and “role-playing” could be used to integrate different historical chemistry topics into classroom teaching. [69] Examined French and Tunisian high school chemistry textbooks' historical implications for effective Daniel cell and electrochemistry teaching. The results showed that a Daniel cell containing two compartments separated by a salt bridge is found to be suitable to teach oxidation-reduction concept. However, the Daniel cell teaching model creates learning difficulty of ionic conduction. Authors suggested that identifying students' prior conceptions and chemical thinking about electrochemical cells using diagnostic tests could help to address electrochemistry concepts.

CONCLUSIONS

In this review, authors mainly focused on examining the high-school students' learning difficulties in learning electrochemistry elsewhere and what instructional strategies aid to attain the students' learning outcomes. To attain this purpose, selection criteria of articles and the methods of analysis for this review was established.

The results of this study revealed that electrochemistry is one the difficult topics for both students and teachers—faced challenges to comprehend concepts such as redox reactions, electric current, electrolytic cell, electrolysis, electrolyte and galvanic cells and entertain misconceptions in these topics. Students' lack of ability to integrate big or core ideas using structure-property relationships; poor background knowledge; absence of teaching aids; misinterpretations of language in scientific contexts; frequent overloading of students' working memory; inability to represent chemical phenomena at the macroscopic, particulate and symbolic levels; the use of concepts and algorithms in a rote fashion without any attempt to understand fully and analyze the problem, and teachers' and textbooks' made misconceptions are the main factors for students' recurrent challenges in studying electrochemistry.

The findings of this review have implications for future research and for planning instructions of electrochemistry in high school classrooms. Experiences of high school students towards electrochemistry teaching around the world revealed that a laboratory work instruction, history and philosophy of science greatly enhanced comprehension of concepts as well as improved students' attitudes. The findings on misconceptions and learning difficulties of oxidation-reduction and electrochemistry are more likely to help teachers and curriculum developers to improve students' conceptual understanding and attract their interest towards chemistry learning.

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