Challenges faced by Chemistry Teachers in Conducting Laboratory-based Activities and their Perceptions on Preparing Cost-effective Chemicals used at Lower Secondary Schools in Rwanda

Jean Baptiste Nkurunziza1, Claude Karegeya[1], Emmanuel Gakuba[1], Ruth Ntihabose[1], Edwige Kampire[2]
[1]University of Rwanda-College of Education, Rwanda, [2]Higher Education Council, Kigali, Rwanda
Corresponding author's email: umwana308@gmail.com

Abstract
The present study aims at identifying the challenges faced by chemistry teachers when planning chemistry laboratory experiments, teachers' perceptions on preparing and using cost-effective chemicals in teaching chemistry and revealing the suitable laboratory procedures to opt when preparing and availing cost-effective chemicals from locally available raw materials. Questionnaires and interview guides were the tools used to collect the research data, while laboratory hands-on activities helped to prepare and avail cost-effective chemicals. These chemicals which include copper sulphate pentahydrate, ammonium chloride, iron sulphate, sodium carbonate, sodium nitrate; hydrochloric acid, sulphuric acid, nitric acid; sodium hydroxide; and acid-base indicators are used to teach basic chemistry concepts such as decomposition reactions, separation of mixtures, acid-base titration, chemical changes. All prepared chemicals displayed the same working effectiveness as their counterpart commercial products. Thus, the prepared cost-effective chemicals can be privileged for hands-on chemistry laboratory activities.

Keywords : Chemicals availability, cost-effective chemicals, laboratory practicals, shortage of chemicals, working Effectiveness

Introduction

The Rwandan education system has adopted a Competence Based Curriculum (CBC) since 2015 which enhances the achievement of skills, attitudes, and values among students. The implementation of CBC requires learners to perform hands-on practical activities. These practical activities which are conducted in the laboratory for chemistry subject provide a particularly attractive opportunity for inquiry-driven and open-ended investigations that promote independent thinking, critical thinking, and reasoning among learners (Bretz, 2019). Through hands-on laboratory activities, learners acquire knowledge and skills to cope with the changing world by placing them at the centre of teaching/learning practices (Otara et al., 2019). Furthermore, laboratory practical activities play a significant role in promoting learners to have positive attitudes and motivation towards learning science subjects (Okam & Zakari, 2017). In addition, practical activities have been shown to help learners improve their communication skills thereby becoming more motivated in learning science subjects (Woolnough, 1994). Therefore, practical work plays a crucial role in promoting science education (Hofstein & Lunetta, 1982; Hofstein & Mamlok-Naaman, 2007). Hands-on laboratory activities are only possible when laboratory materials and chemicals suitable for the desired experiments are available to secondary schools. However, due to financial constraints, the use of modern equipment and chemicals in many secondary schools is still challenging. Thus, many schools from developing countries are not well equipped with basic laboratory equipment and chemicals. For example, as of 2019, the science laboratory equipment in Rwandan secondary schools was at 25.5% (455 out of 1523 secondary schools), according to MINEDUC (2019).

One way to deal with this paradox challenge is to build the capacities of secondary schools' chemistry teachers to prepare and avail themselves cost-effective chemicals from locally available raw materials. Thus, there should be a shift from importing expensive chemicals from abroad and relying on the prepared cost-effective chemicals made by using locally available cheap resources. In this perspective, the present research intends to bridge the above-stated gap of shortage of laboratory materials by focusing on availing cost-effective chemicals from locally available raw materials.

Review of literature

According to Yitbarek (2012), low-cost or cost-effective materials refer to cheap materials made from locally available resources. Low-cost materials can be obtained at no cost or low cost in terms of money. In this research context, cost-effective chemicals are defined as the ones available in the natural and immediate environment to teachers as well as scraps/discards from commercial and domestic use which can be used without further modification or treatment, or chemicals which can be locally made using cheap locally available raw materials. Typical examples include discarded copper wire for copper metal, pure nail for iron metal, pure white chalk based on calcium carbonate for calcium carbonate, car battery acid for sulphuric acid, table salt for sodium chloride, locally made copper sulphate, nitric acid, and hydrochloric acid from copper wire, nitrate fertiliser, and table salt each one with car battery acid respectively.

The production of cost-effective chemicals was reported by many authors (Cloete et al., 2021; El-Gendi et al., 2022; Li et al., 2020; Sakhuja et al., 2021; You et al., 2018). However, none of these authors intended to make and avail cost-effective chemicals to be used in the educational sector, hence practical consideration to produce and avail cost-effective chemicals for teaching and learning chemistry should be given priority. This is because cost-effective chemicals may offer many advantages when teaching and learning chemistry. Cost-effective chemicals are less expensive than their more expensive counterparts, making them an affordable option for educational institutions that may have limited budgets. By using cost-effective chemicals, more students may have access to hands-on chemistry education. This is possible as they are more affordable for educational institutions, hence students can use them for experiments and demonstrations at an affordable price. Cost-effective chemicals can be sourced locally, reducing the time needed to procure them and making it easier for students to repeat experiments. Thus, the availability and use of cost-effective chemicals can help educational institutions provide quality education at a lower cost while still ensuring the safety and effectiveness of the experiments. Cost-effective chemicals may help learners to develop practical skills through hands-on laboratory activities which are one of the Learner-Centred Instructions (LCI) initiated by the constructivist theory of learning (Baeten et al., 2010).

In response to the approach of LCI in Rwanda, some educational development partners to the Ministry of Education (MINEDUC), like the Flemish Association for Development Cooperation and Technical Assistance (VVOB), Voluntary Service Overseas (VSO), provide technical and financial support that serve to build the teacher's capacity at all educational levels toward the implementation of LCI. In addition, the Government of Rwanda has put tremendous efforts and more emphasis on developing 21st century skills and preparing students to enter the modern market. However, the quality of teaching and learning cannot be achieved when the challenges faced by teachers while delivering course subjects are not solved. Therefore, the researchers conducted this research to identify the main challenges encountered by the teachers while planning or delivering chemistry laboratory activities and then proposed practical strategies to overcome them.

As the lack of laboratory materials and chemicals was reported as one of the key challenges preventing teachers from conducting chemistry laboratory activities, the researchers were interested in bridging that gap. Thus, the researchers prepared and availed cost-effective chemicals from cheap locally available raw materials for the enhancement of teaching and learning of chemistry, and the approved methods are reported. The following research questions guided the study:

1. What are the challenges faced by chemistry teachers while planning or conducting chemistry laboratory experiments in their teaching?
2. What are the teachers' perceptions on availing and using cost-effective chemicals in teaching and learning of chemistry?
3. What are the suitable methods to be opted for when preparing cost-effective chemicals from cheap locally available raw materials?

Methodology

Research design

The study adopted an explanatory research design to identify the main challenges encountered by chemistry teachers when planning and delivering chemistry experiments to propose viable solutions. This design was suitable for the research as it is an easily accessible way for respondents to share or demonstrate their knowledge or perspectives about a particular topic. In addition, this approach can allow for researchers to gain a better understanding about any challenges or concerns the respondents have, which may lead to the identification or development of solutions based on identified issues. This design used a mixed data collection method (both quantitative and qualitative).

Population and sampling

The target populations of the study were all ordinary level chemistry teachers from selected districts of Rwanda which are Musanze, Rubavu, Huye, Rwamagana, Gasabo and Kicukiro. The sample was purposively selected from the population and was made up of all 35 ordinary level chemistry teachers from 19 selected secondary schools within the above-stated districts. Schools were selected by ensuring that each district is represented by at least one boarding and one non-boarding school. Prior to undertaking this research, the UR-CE (Ethical Committee) provided ethical clearance and approved a formal informed consent form which was completed by every teacher participating in the study. Participants' distribution and sample size are given in Table 1.

Table 1

Participants' distribution and sample size

Province/District	No. of schools	No. of teachers	
		Male	Female
Kigali city/ Gasabo & Kicukiro	4	6	1
East/ Rwamagana	3	4	0
West/ Rubavu	4	7	3
North/ Musanze	4	4	3
South/ Huye	4	6	1
Sub/Total	19	27	8
Grand Total	**19**	**35**	

Research Instruments, Data collection and Data Analysis

The questionnaire and interview guides for teachers are the tools used to collect data for answering the first two research questions. The questionnaire was preferred in this research because it is suitable for measuring the phenomenon under study in statistical or numerical ways without bias (Burcu, 2000). In addition, the questionnaire was suitable to collect information about the frequency of conducting chemistry laboratory experiments, as well as revealing the main challenges that chemistry teachers encounter when planning or conducting laboratory experiments. The questionnaire for teachers was made up of fifteen closed questions, whereas interview guide for teachers was made of six open questions. Both questionnaire and interview guide were validated by a team of three chemistry lecturers' experts from University of Rwanda-College of Education (UR-CE). The researchers piloted the questionnaire on a sample of four teachers from two secondary schools which were not taking part of the sampled schools to establish whether the adapted instruments would give similar results. The questions were then adapted where necessary. Interviews with chemistry teachers helped the researchers to get insights about teachers' perceptions on availing and using cost-effective chemicals for enhancing teaching and learning chemistry subjects. The collected data from questionnaires were analysed quantitatively using Excel, whereas the interviews' data were analysed with an interpretive approach. Furthermore, laboratory experiments were carried out for the researchers to answer the third research question, where suitable methods for preparing and availing cost-effective chemicals were validated. The working effectiveness and cost-effectiveness of locally made chemicals were analysed respectively by comparing the working efficiency and production gain of locally made chemicals with their counterpart commercial chemicals.

Methods of making cost-effective chemicals

In this study, the researchers prepared different cost-effective chemicals needed for carrying chemistry experiments such as the preparation of copper sulphate crystals; determination of acid & base properties; determination of colour changes in indicators; and investigation of the action of heat on nitrates or sulphates. Thus, the researchers reviewed all needed chemicals from ordinary level chemistry syllabus, then selected priority chemicals to be made, the ones which are mostly needed in many laboratory activities. The identified chemicals were copper sulphate pentahydrate, ammonium chloride, hydrochloric acid, sulphuric acid, nitric acid, sodium hydroxide, acid-base indicator, sodium carbonate, iron sulphate, and sodium nitrate. The identification of the chemicals to be made was followed by a comprehensive literature search using multiple search engines such as Google, Google Scholar, and YouTube where keywords such as "making cost-effective chemicals", "procedure for making affordable chemicals", "homemade low-cost chemicals", and "homemade economic chemicals" were used. In this way, the researchers were able to develop appropriate procedures to make cost-effective chemicals using cheap locally available raw materials (Table 2). The synthesis of cost-effective chemicals was done in the chemistry laboratory of the University of Rwanda-College of Education.

Table 2

Methods for preparing cost-effective chemicals for chemistry experiments

S/No	Synthesized chemicals	Source of normal products at lab-scale	Source of cost-effective products at lab-scale
1	Copper sulphate pentahydrate	From the reaction between copper metal with dilute sulphuric acid (Marsh & Marsh, 1934).	From electrolysis of car battery acid using copper electrodes
2	Hydrochloric acid	From sodium chloride and concentrated sulphuric acid (Nachod & Shapleigh, 1949; Stauffer, 2004)	From table salt and car battery acid
3	Ammonium chloride	From the reaction between hydrochloric acid with ammonia (Wilheim, 1938)	From cost-effective hydrochloric acid and cost-effective ammonia
4	Sulphuric acid	Electrolysis of calcium sulphate (Van Denbergh, 1900)	Electrolysis of cost-effective copper sulphate
5	Sodium nitrate	From sodium carbonate or bicarbonate with nitrating agents (Stengel, 1950)	From the reaction between Calcium Ammonium Nitrate (CAN) fertilizer with caustic soda
6	Nitric acid	From sodium nitrate with concentrated sulphuric acid (De Jahn, 1912)	From the reaction between nitrate fertilizer (prepared cost-effective sodium nitrate) with car battery acid

7	Sodium hydroxide	Electrolysis of aqueous solution of sodium chloride (Osborne & Miller, 1961)	Electrolysis of aqueous solution of table salt
8	Sodium carbonate	From the reaction between NaOH and CO_2 (Tasiaux, 1965)	Converting baking soda into sodium carbonate through heating (Helmenstine, 2021).
9	Iron sulphate	From the reaction between iron and sulphuric acid (Mattia & Sakler, 1973).	From the reaction between nails with car battery acid
10	Acid-base indicators/ Litmus papers	Synthetic acid-base indicators/ Litmus paper	From beetroot using water as the solvent (Acid base indicators made), and from Hibiscus sabdariffa flowers (litmus paper indicator) (Ncutinamagara et al., 2023).

As shown in table 2 above, cost-effective chemicals were made starting from cheap locally available resources. As an example, copper sulphate pentahydrate was synthesized by electrolysis of car battery acid using discarded copper wire as electrodes following the literature procedure reported by Helmenstine (2019). Sodium carbonate was made from locally available baking soda (Helmenstine, 2021). Cost-effective iron sulphate was availed from the reaction between locally available raw materials which are nails with car battery acid using a slightly modified procedure reported by Mattia & Sakler (1973), while cost-effective sodium nitrate was made from locally available CAN fertiliser with cost-effective caustic soda locally sold as drain opener (The Canadian chemist, 2023). Cost-effective nitric acid was prepared by reacting locally made cost-effective sodium nitrate with car battery acid using a modified procedure reported by De Jahn (1912). Cost-effective ammonium chloride was prepared by the combination reaction between the prepared cost-effective hydrochloric acid and ammonia solution. The ammonia solution was in turn made from urea fertilizer with caustic soda which is locally sold as a drain opener. Cost-effective sodium hydroxide was prepared via electrolysis of an aqueous solution of table salt using a developed double-chamber electrolytic cell.

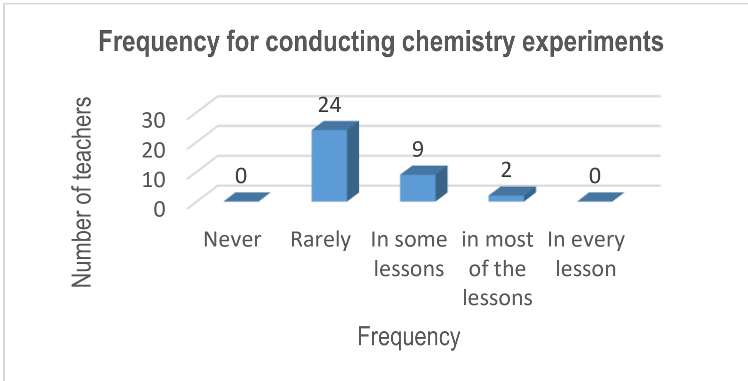
Results and discussions

Frequency of conducting chemistry experiments and challenges associated to them

To gather the above data, teachers were asked to reveal the status of conducting laboratory activities by answering this question “In your teaching career, how often do you organize practical laboratory/hands-on activities in your chemistry classes”. The answers from the respondents are summarized in Figure 1.

Figure 1

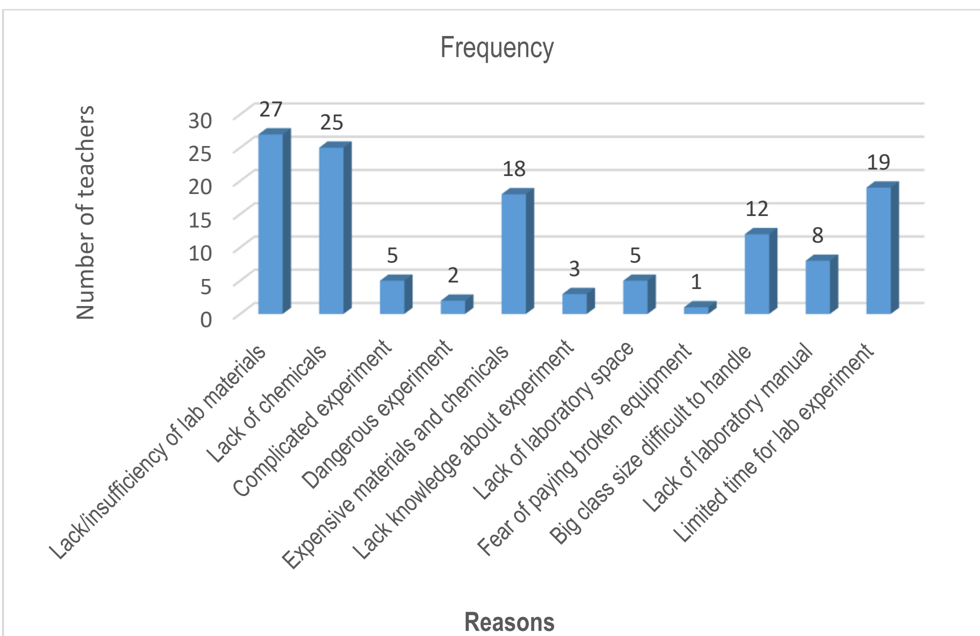
Frequency of conducting chemistry experiments



The above data shows that none (0%) of the teachers is organizing laboratory sessions in every lesson; 9 (26%) organize them in some lessons, while 24 (68%) organize them rarely. Thus, many teachers do not organize chemistry laboratory practical sessions at a satisfactory level. The teachers were then asked to disclose the reasons for not conducting some of the laboratory experiments, and the research findings are given in Figure 2.

Figure 2

Reasons for not conducting chemistry laboratory activities

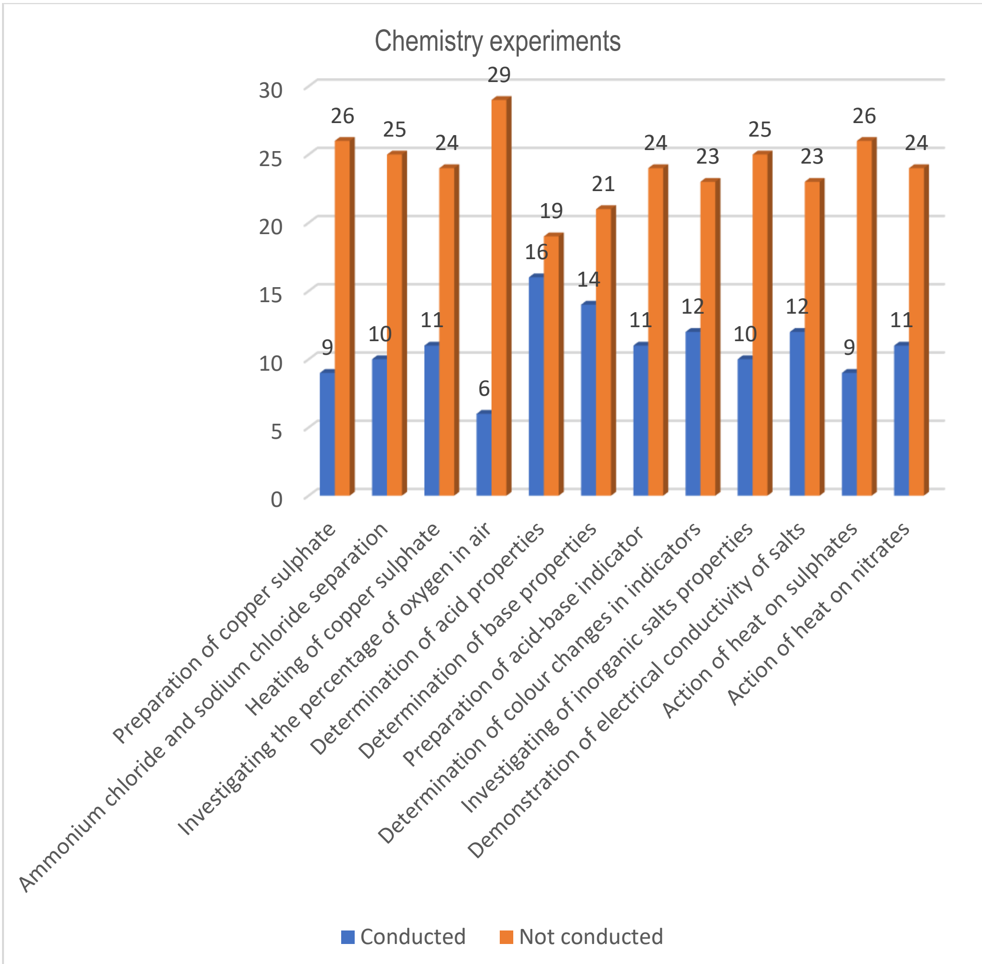


From Figure 2 above, the lack or insufficiency of laboratory materials (77%), lack of chemicals (71%), and expensive materials and chemicals (51%) are the main factors hindering teachers from conducting laboratory practical sessions.

The researchers were then interested in knowing which types of experiments are not easily conducted by the teachers due to the above-mentioned challenges. The highlighted answers are given in Figure 3.

Figure 3

Frequency of conducting/non-conducting chemistry experiments



From the above results, it is evident that many teachers are unable to conduct all planned chemistry experiments. For example, 26 (74%) and 24 (68%) teachers did not respectively conduct the preparation of a big crystal of copper sulphate and investigate what happens when copper (II) sulphate is heated. This was due to the lack of copper (II) sulphate at their schools. Similarly, 26 (74%) teachers failed to demonstrate the action of heat on sulphate due to the lack of any sulphate such as iron or copper sulphate at their schools. Similarly, 24 (68%) teachers did not perform the reaction about the action of heat on nitrates due to the absence of any nitrate such as sodium nitrate. 19 (54%) and 21 (60%) teachers failed to demonstrate the properties of acids and bases respectively, as acid chemical products such as hydrochloric acid, sulphuric acid, and nitric acid; base chemical products such as sodium hydroxide; and acid-base indicators are missing at their schools. Thus, the lack of chemicals such as copper sulphate pentahydrate, ammonium chloride, hydrochloric acid, sulphuric acid, nitric acid, sodium hydroxide, acid-base indicator, sodium carbonate, iron sulphate, and sodium nitrate was found to be one of the factors that prevented the teachers from conducting chemistry laboratory experiments. To bridge the above-mentioned gap of lacking or insufficiency of chemicals, the researchers stepped forward by producing and availing the same chemicals from cheap, and locally available raw materials. The produced chemicals were found to be cost-effective when compared with the same commercially available standard chemicals. The lack or insufficiency of chemicals in many secondary schools is not newly reported. The study conducted by (Hassan et al., 2017; Nsanzimana et al., 2021) revealed that the lack of laboratory apparatus and chemicals is one of the factors hindering the effective teaching and learning of chemistry at secondary schools. This limits the number of experiments that teachers can conduct in the classroom, leading to limited practical sessions (Shana & Abulibdeh, 2020). Furthermore, the lack of chemicals prevents learners from acquiring some practical chemistry skills, thus depriving them of critical competencies that are required for success in the subject (Fadzil & Saat, 2017). In addition, the lack of chemicals in secondary schools hinders learners' research opportunities, especially those who could carry out independent research projects. This limits their ability to learn through discovery, which is a critical component of scientific research. Therefore, special measures should be taken to ensure the provision of chemicals to schools so that learners are equipped with the necessary skills and knowledge required to succeed in the subject and apply them in real-life situations. From the researchers' side, our contributions focused on the preparation and availing of cost-effective chemicals from locally available raw materials for effective teaching and learning of chemistry.

Teachers' perceptions on availing and using cost-effective chemicals in teaching and learning of chemistry

The researchers had an interview with the teachers to get their perceptions on preparing, availing, and using cost-effective chemicals. Firstly, the teachers were requested to express what they know about cost-effective chemicals and their comments were recorded appropriately. Twenty teachers (57%) said "*We heard about low-cost materials, but we don't have more information about cost-effective chemicals. We have never seen them*". The remaining teachers (43%) said that they can define them literally as "*Chemicals which are not expensive, but capable of achieving the same learning outcomes as the standard expensive ones. However, we don't know how to make them, and we have never used them in teaching*".

Based on the information above, none of the interviewed teachers had used cost-effective chemicals when teaching and learning chemistry concepts. This invited the researchers to take some time to give more explanations and clarifications to interviewed teachers about cost-effective chemicals. Explanations were supported by the provision of concrete examples. After having the same understanding of cost-effective chemicals, the researchers were interested in knowing the teachers' perceptions on preparing, availing, and using cost-effective chemicals in teaching and learning chemistry. All interviewed teachers appreciated the idea. For example, teacher 5 said "*The availability of cost-effective chemicals will help me to effectively teach many chemistry concepts than I am doing currently. My students will gain both theoretical and practical skills. Thus, I am glad to learn how to make cost-effective chemicals*".

Another teacher 8 said "*I and my students will benefit more from cost-effective chemicals' availability. I will be able to conduct many experiments and help my students to understand many chemistry concepts. As an example, the availability of cost-effective copper sulphate pentahydrate will help me to clarify the decomposition reactions concept, and crystallization process which is one of the methods for the separation of mixtures*".

The teachers highlighted that they will not only gain in terms of conducting many experiments. They added that the process of preparing cost-effective chemicals will help them as well as their students to improve creativity and innovations. This was supported by one of the statements from teacher 18 who said "*The availability and use of cost-effective chemicals will encourage students and teachers to think creatively and to be resourceful, as we are required to work with what is available. This will help us develop problem-solving and critical thinking skills, which are essential in the study of chemistry*".

Working effectiveness of prepared cost-effective chemicals

The working effectiveness of prepared cost-effective chemicals against the same standard commercial chemicals was investigated by comparing their chemical reactivities while performing various chemical reactions. The results are given in Table 3.

Table 3

Comparison of the working effectiveness of prepared cost-effective chemicals versus standard chemicals

Chemicals	Name of the reaction	Working Effectiveness in terms of chemical reactivity	
		Observation on Cost-effective Chemicals	Observation on Standard Chemicals
Concentrated ammonia solution	Diffusion of gases when ammonia reacts with hydrochloric acid	White fumes observed	White fumes observed.
Hydrochloric acid	Diffusion of gases when hydrochloric acid reacts with ammonia	White fumes observed	White fumes observed
Sodium hydroxide	Acid-base properties by testing the colour change using red litmus paper	Red litmus paper changes to blue	Red litmus paper changes to blue

Hydrochloric acid	Acid-base properties by testing the colour change using red litmus paper	Red litmus paper didn't change its colour	Red litmus paper didn't change its colour
Copper sulphate pentahydrate	Decomposition reaction on heat	The blue colour of the product changed to white	The blue colour of the product changed to white
Sodium nitrate	Decomposition reaction on heat	Released gases don't change wet red litmus paper	Released gases don't change wet red litmus paper

The results of the reactions mentioned in the table above show that the reaction characteristics as well as their products for both cost-effective and commercial chemicals are similar. It therefore concluded that their working effectiveness is the same. The above results were supported by the views of teachers who used the prepared cost-effective chemicals in their teaching. As an example, teacher 22 said "*I and my students used cost-effective ammonia and hydrochloric acid to demonstrate the diffusion of gases concept. The reaction was faster than we could imagine. White fumes appeared directly, and my students well understood the concept. Thus, prepared cost-effective chemicals helped us to clarify abstract concept like gas diffusions*". Another teacher 34 said "*I taught the identification of copper and iron ions in each of the given unknown solutions using the prepared cost-effective chemicals. My students performed the reactions. Upon the addition of sodium hydroxide solution to each of the above unknown solutions, a blue and green precipitates were formed respectively as were expected*". Therefore, cost effective chemicals are as suitable as their commercial counterparts for conducting laboratory activities during chemistry teaching and learning.

Cost-benefit analysis of produced chemicals

The production cost gain of prepared chemicals against the same commercial counterpart products was calculated using the expression below, and the results are given in Table 4. Note that the commercial prices were given in Euros (€), then converted into Rwandan Francs (Frw), using the convertor link: https://www.currency.me.uk/convert/eur/rwf

Production cost gain = $\frac{(Price\ of\ standard\ chemical - Price\ of\ low\ cost\ chemical)}{Price\ of\ standard\ chemical}\ X\ 100\%$

Table 4

Cost-benefit gain of prepared cost-effective chemicals

S/No	Low-cost price/ Frw	Commercial price/ Frw (€); Reference as of 19.05.2023	Production Gain
1	**Ammonium chloride: NH_4Cl/ 500 g**		

	54,300 Frw	75,537 Frw (€62.40) (Sigma, 2023a)	28.1%
2	**Copper sulphate pentahydrate: $CuSO_4.5H_2O$/ 500 g**		
	55,620 Frw	117,784 Frw (€97.30) (Sigma, 2023b)	52.7%
3	**Iron sulphate: $FeSO_4.7H_2O$/ 250 g**		
	12,000 Frw	39,705 Frw (€32.80) (Sigma, 2023c)	69.7%
4	**Hydrochloric acid: HCl/ 500 ml**		
	28,630 Frw	86,552 Frw (€71.50) (Sigma, 2023d)	66.9%
5	**Nitric acid: HNO_3/ 500 ml**		
	60,000 Frw	239,684 Frw (€198.00) (Sigma, 2023e)	74.9%
6	**Sodium carbonate: Na_2CO_3/ 500 g**		
	21,375 Frw	66,942 Frw (€55.30) (Sigma, 2023f)	68.0%
7	**Sodium hydroxide: NaOH/ 25 g**		
	12,900 Frw	25,542 Frw (€21.10) (Sigma, 2023g)	49.4%
8	**Sodium nitrate: $NaNO_3$ /500 g**		
	18,300 Frw	76,263 Frw (€63.00) (Sigma, 2023h)	76.0%
9	**Sulphuric acid: H_2SO_4/ 500 ml**		
	20,550 Frw	79,047 Frw (€65.30) (Sigma, 2023i)	74.0%

The above results show that all the prepared chemicals are cost-effective when compared with the same commercially available chemical products. As an example, there is a production gain of 52.7% when 500g of cost-effective copper sulphate pentahydrate is made. Similarly, 500 g of prepared cost-effective sodium carbonate is costing 21,375 Frw with a cost gain of 68.0% when compared with the same commercially available product which is sold at 66,942 Frw (€55.30). The above observations show that the production cost can be reduced by using cheap, and locally available raw materials. Our findings are supported by other researchers' discoveries. As an example, a study conducted by Banat et al. (2014) on low-cost, renewable raw substrates and fermentation technology in biosurfactant/ bioemulsifier production revealed that low-cost and efficient use of raw materials can significantly reduce the production costs of chemicals. Other studies which focused on the use of low-cost chemicals in textile dyeing processes identified some cost-effective chemicals, including sodium bicarbonate and urea, and their uses gave promising results in reducing the costs of textile dyeing (Kumar & Suganya, 2017). In the field of pharmaceuticals, Lee et al. (2009) reported the use of inexpensive substrates which helped in achieving cost-effective drug development. Similarly, low-cost substrates for the synthesis of cost-effective mannitol were reported by Zhang et al. (2018). The above results agree with our findings which stipulate that cost-effective chemicals synthesis can be achieved using cheap, and locally available raw materials.

Conclusion and recommendation

The findings from the current study revealed the availability of cheap raw materials and effective laboratory procedures to be used while preparing and availing cost-effective chemicals. The prepared chemicals displayed the same working effectiveness as the same standard commercial products. The production cost-gain analysis showed that all the prepared chemicals are cost-effective. All interviewed ordinary-level chemistry teachers appreciated the approach of using cost-effective chemicals to clarify many chemistry concepts which seem to be abstract in nature. Thus, preparing and availing cost-effective chemicals can be regarded as one of the strategies to boost hands-on chemistry laboratory activities in many schools, especially in those which are having budget constraints. The research outputs suggest that substantial consideration to train secondary school ordinary-level chemistry teachers on how to prepare and avail cost-effective chemicals for enhancing the teaching and learning of chemistry be given priority. Secondary school teachers are encouraged to be more innovative and creative to discover how other non-reported chemicals can be prepared at low-cost and made available in their schools using cheaply available resources.

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