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Impact of Using Low-cost Materials for Effective Teaching and Learning Chemistry at Lower Secondary Schools in Rwanda

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Abstract: *The purpose of the study was to assess the impact of using low-cost materials for effective teaching and learning chemistry in lower secondary schools. The study was guided by one objective which was: To determine the effectiveness of using low-cost materials on learners' academic performance in teaching and learning Acids, Bases, and pH at lower secondary schools. The study included a sample of Senior One chemistry students from four schools and four teachers from Ngoma District of Rwanda. Using a quasi-experimental research design, these students were divided into control group (n = 58) and experimental groups (n = 56). Students in the experimental group received treatment utilizing low-cost materials in chemistry lessons. In contrast, in the control group, students were taught via traditional methods, where they utilized textbooks. The data were analysed using the Statistical Package for Social Sciences (SPSS). The results showed that students in the experimental group who were given instruction utilizing low-cost materials in lessons outperformed those in the control group in the academic achievement test with a high effect size. Therefore, using low-cost materials may improve students' achievement.*

Key words*: Acids, Bases, Beetroot indicators, Litmus paper, Learning achievement*

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1. Introduction

Chemistry is the science concerned with the study of matter and its transformations. It is the branch of science that deals with the study of the properties and behaviour of matter (Brown et al., 2022). This enabling science is at the heart of nearly every branch of modern science and technology, particularly the new and exciting inter- and multi-disciplinary fields of molecular genetics, molecular biology, nanotechnology, medicinal chemistry, drug design and development, and green (environmentally sustainable) chemistry and industry (Balaban & Klein, 2006).

Educators and academicians have explored the significance of experiment and its importance in chemistry subject since the beginning of the 18th century (Shana & Abulibdeh, 2020). Several studies have shown that experiment has numerous benefits, including the development of laboratory skills and scientific knowledge, as well as the comprehension of scientific concepts and theories (Fadzil & Saat, 2017).

According to Robert (2019), in supporting the experiment laboratory in the scientific field said that: "Students achieve a deeper level of understanding by finding things out for themselves and by experimenting with techniques and methods that have enabled the secrets of our bodies, our environment, and the whole universe – to be discovered." According to Okam and Zakari (2016) experiment plays an important role in increasing the positive attitude of students. In another research, experiment has also been found to assist students in developing their communication skills in order to solve issues in science and thus become more interested in science (Fong & Kwen, 2007).

According to Ndihokubwayo (Ndihokubwayo, 2017), the practical work is not easy to organize due to a lack of laboratory apparatus. Even though this is occurring, academics urge for a shift away from rote learning and toward inquiry activities and problem-solving, as well as a shift away from teacher-centered to student-centered approaches. The laboratory equipment and learning materials are expensive and funds are not readily available (Cossa & Uamusse, 2015). For instance, in Rwanda, the science laboratory equipment in secondary schools is at 25.5% (455 out of 1523 secondary schools) (MINEDUC, 2019). Table 1 shows the number of schools that had equipped science laboratories from 2016 to 2019.

Table 1: Number of schools with science laboratories

Indicators /year	**2016**	**2017**	**2018**	**2019**
Number of schools with science laboratory	346	338	338	455
Percentage of schools with science laboratory	22.0%	21.6%	21.6%	25.5%

Source: Education statistical yearbook 2019 (MINEDUC, 2019).

This shows that conducting these practical experiments still presents a barrier due to the lack of available lab space and equipment. As a result, it is necessary to look for an alternative, cheaper materials that could be used in teaching and learning to help students practice those subjects they consider to be challenging. This issue might be resolved using low-cost materials or virtual labs, which are more affordable than construction and stocking actual labs.

According to Rwanda's education statistical yearbook (MINEDUC, 2019), the quality and availability of science laboratories have an impact on students and teachers' achievement at all levels of education. Research shows that science laboratory has an impact on students' academic performance at school, as well as their learning experience in terms of motivation, progression, independence, and interaction. The availability of laboratory equipment and chemicals is one of the variables that facilitate the process of teaching and learning science in both developing and developed countries (Uzezi & Zainab, 2017).

Kibirige & Hodi (2017) stablished that learners performed better in physical sciences when taught using laboratory investigations compared to those taught without. A study in Rwanda by Twahirwa and Twizeyimana (2020) found out that a group of learners that was taught physics using practice-based approach outperformed those that used the expository approach. Teachers have to develop and use locally available materials to clarify scientific theories and allow learners to participate in science innovation. Therefore, this study sought the impact of using low-cost materials for effective teaching and learning Acids, Bases, and pH in lower secondary schools in Rwanda.

The specific objective:

- ❖ To determine the effectiveness of using low-cost materials on learners' academic performance in teaching and learning Acids, Bases, and pH at lower secondary schools.

2. Literature Review

Since the late 1800s, scientific educators have thought that a laboratory is a vital tool for teaching science. Laboratory instruction was considered necessary because it provided observation training, and precise information, and attracted students' attention**.** In a laboratory, students work on a subject, problem, or hypothesis individually or in small groups. They develop their explanations of scientific events using scientific techniques and materials (Hamidu et al., 2014)**.** The laboratory learning setting is essential in science education because it provides students with an experience that is different from the traditional classroom. Students' understanding of scientific concepts, problem-solving skills, and attitudes toward science will all benefit from laboratory practice (Ahmad et al., 2014). Low-cost materials are materials developed and produced from locally available resources to support efficient teaching and learning in classrooms. When the original or ideal materials are not available, these low-cost materials can be employed to achieve the same learning results that the regular materials would have since they are as effective as the standard materials (Twizeyimana et al., 2020). In the educational system, using the low-cost material serves the following purposes: it reduces the money spent on purchasing equipment in educational institutions, it ensures the achievement of lesson objectives, it allows teachers to demonstrate their creative abilities while also encouraging students to develop creative abilities, it strengthens the inquiry, discovery, and investigative method in sciences by allowing teachers to think of cheaper, better, and faster solutions, and it strengthens the inquiry, discovery, and investigative method in sciences by allowing teachers to think of cheaper, better, and faster solutions (Ndihokubwayo, 2016).

Supriyanti and Halimatul (2018) designed a color chart of acid-base indicators using extracts from local plants to help in chemistry teaching and learning. For the study, the local environment's flower plants and leaves were obtained. In the study, it was mentioned that plants are known to have pigments like anthocyanin, which gives their fruits, flowers, leaves, stems, and blooms color. The color chart's layout aided classroom instruction on acids and bases. Moreover, due to their easy accessibility in the environment, the usage of these materials reduces issues about breaking, repair, and loss. It makes teachers and students aware that there are alternatives to some of the common science teaching resources. Additionally, it demonstrates that individuals are capable of conducting scientists using the resources available to them. One most important benefits of using low-cost materials for experiments is that it allows students to actively engage in the creation of the apparatus and increases their understanding of how such materials function.

3. Methodology

This study used a quasi-experimental design in that it used random assignment to divide the population into two groups: an experimental group that received the intervention and a control group that didn’t receive an intervention. Quantitative research was conducted to answer the research objective and question addressed in this study.

The study's experimental setup was divided into three steps: Pre-test, experiment, and post-test. Students were asked to fill out questionnaires about their prior knowledge of low-cost materials during the pre-test. For the experiment part, the students were divided into two different groups designated as control group, and the experimental group. For the topic of "Acids, Bases, and pH", the Control group learned lessons without materials, while the experimental group learned the lesson by using low-cost materials.

After the experiment, both groups responded to questionnaires to assess the effectiveness of the low-cost materials (Beetroot indicator and litmus paper) for teaching the concept of Acids, Bases, and pH.

Procedure

Pre-test

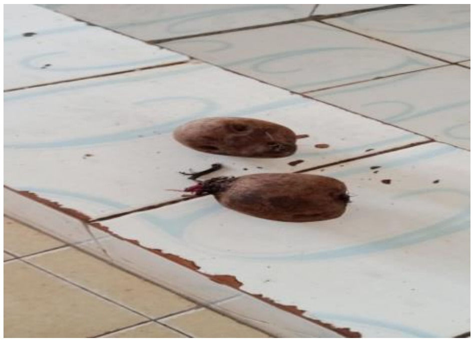
The use of low-cost materials (beetroot indicator and litmus paper) was first discussed with teachers to learn more about their knowledge and opinions on that topic. Students who took part in the experiment were given questionnaires to complete before the studies proceeded. Answers from the questionnaire were recorded, scored, and analyzed.

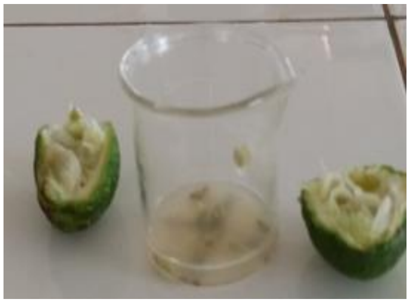
Design of experiments

All students in the experimental group and their teachers participated in the experiment. Before starting the experiment, participants were taken thorough the steps involved. The litmus paper and acids-bases indicators were designed and produced from beetroot and hibiscus sabdariffa. Pieces of beetroot were made from it. Pieces were placed in a pot with just enough water to cover them, and it was then cooked for 45 minutes. Boiling and allowing the liquid to cool produced a blue-violet pigment that was used as an acid-base indicator. Litmus paper was made from fresh hibiscus sabdariffa where duplicate paper form A4 was used by putting the fresh pigment on duplicate paper then dry it on sun light for about 10 minutes. After that, the paper was cut into small parts similar to standard litmus paper.

The above locally made materials were then used to test different solutions by adding a few drops of beetroot juice to each solution to determine whether the solution was an acid or a base and students were able to note their findings based on the color shift. Furthermore, the improvised litmus paper was used to test each solution for being acid or base, and the results were recorded.

Procedure of making indicator from beetroot

 *Figure 1*: beetroot	 Figure 2: cut beetroot into small pieces	 Figure 3: small pieces of into pot, boil it around 45min and cool it.

 *Figure 4: Juice from lemon*	 *Figure5: Juice from orange*	 *Figure6: Juice from pineapple*
 *Figure7: Juice of beetroot into juice of lemon*	 *Figure8: Juice of beetroot into juice of orange*	 *Figure9: Juice of beetroot into juice of pineapple*

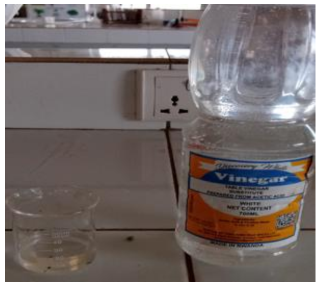
<table>
<tr>
<td>
Figure10: Wood ash</td>
<td>

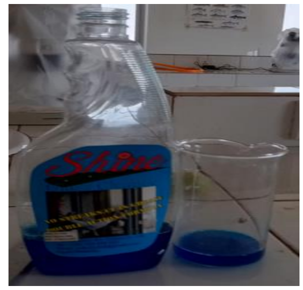
Figure11: Vinegar</td>
<td>

Figure12: Cleaning soap</td>
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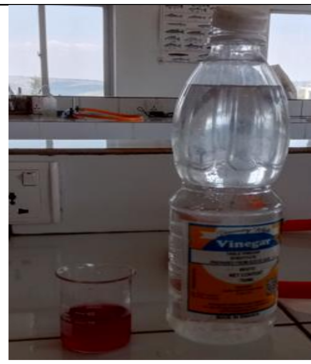
Figure13: Juice of beetroot into wood ash</td>
<td>

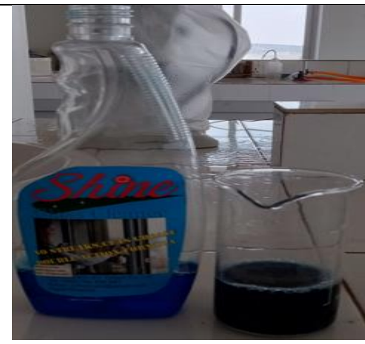
Figure14: Juice of beetroot into vinegar</td>
<td>

Figure15: Juice of beetroot into cleaning soap</td>
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Procedure of making litmus paper

Figure 5: White sheet

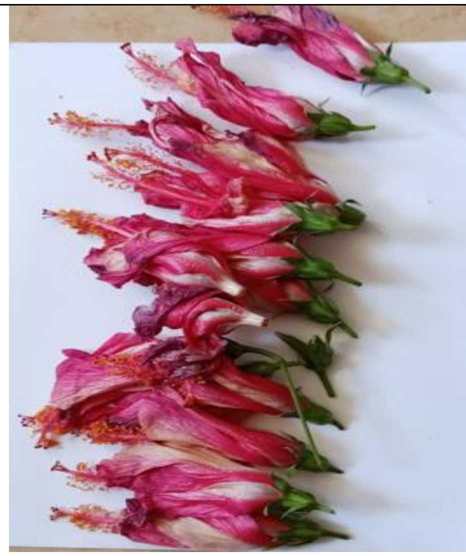

Figure 6: Flowers from hibiscus

Figure 7: put pigment of flower on white

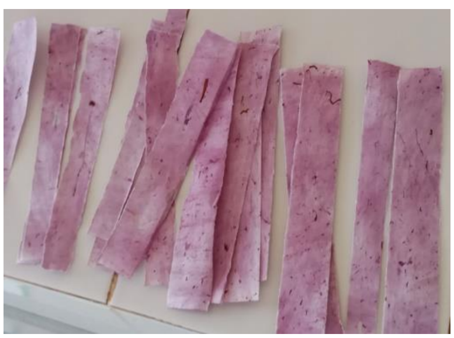

Figure 8: cut the paper in the same shape and same size

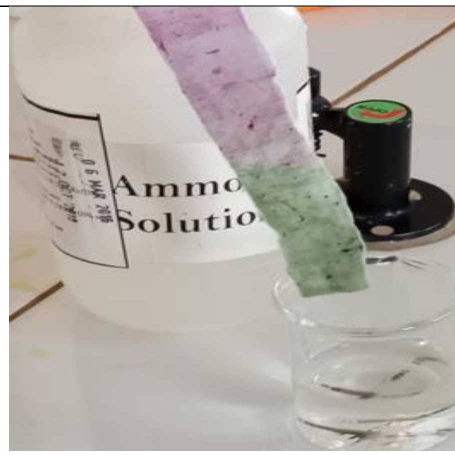

Figure 9: litmus paper into solution of Ammonia

Figure 10: litmus paper into potassium hydroxide

Figure 11: litmus paper into vinegar

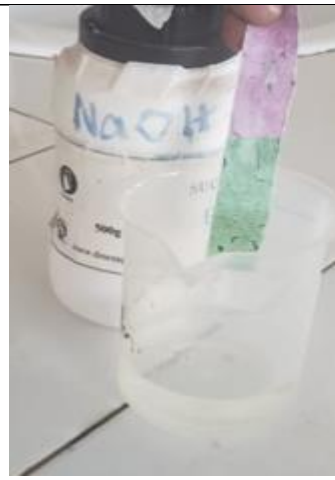

Figure 12: litmus paper into sodium hydroxide

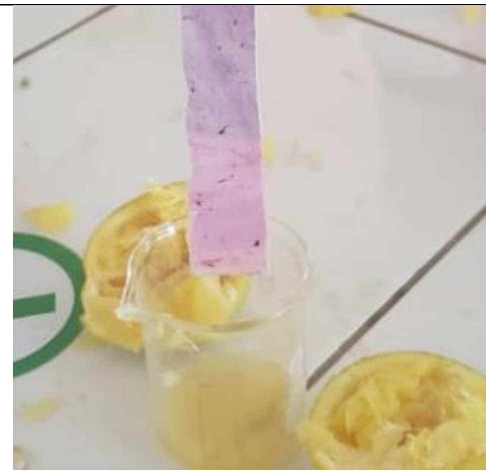

Figure 13: litmus paper into orange juice

Post-test

The purpose of the post-test was to determine how well the low-cost materials explained the concept of acids, bases and pH. After the experiment, students who had taken part in were given another questionnaire to complete about the usefulness of low-cost materials and whether they had the same educational impact as standardized educational materials.

Data collection methods

Data was gathered using a chemistry Achievement Test (CAT). The assessments were objective tests that included mainly five questions with 30-item, conceptually focused open-ended and closed-ended questions on the topic of Acids, Bases, and pH, respectively. 114 randomly selected senior one student from four ordinary level secondary schools in Ngoma District took the test. The scores from the Chemistry Achievement Test (CAT) for both pre and post-tests from the two study groups were entered into excel sheets later to be transferred to SPSS. The descriptive statistics of interest included mean, standard deviation, standard error, and range. The independent sample T-test was performed to see if there were any statistically significant differences in the pretest and post-test mean scores within groups. All of these tests were carried out at 95% confidence intervals.

Data analysis

Since the data was collected at the same time, the data was analyzed in terms of the two categories of data involved in this study. Data input and statistical computations of the questionnaire items were done using Statistical Package for Social Sciences (SPSS) before the data was analyzed. That process included coding data and editing, identifying, and eliminating some errors made by the participants.

4. Results and Discussion

The effectiveness of using low-cost materials for effective teaching and learning Acids, bases, and pH concepts.

The study was intended to determine the effectiveness of using low-cost materials for effective teaching and learning Acids, Bases, and pH. To respond to this research question, the research data were collected using the Chemistry Achievement Test (CAT)-pre-test and posttest on senior one student in four schools. The 114 participants' data were descriptively analyzed using SPSS.

Descriptive statistics on Academic Achievement

The test scores ranged from 0 to 30, with higher scores indicating better academic achievement. Learners in both groups did a pretest before treatment and a post-test at the end of the treatment period.

Table 2: Pretest and Post-test scores

Treatment		CAT Scores			
	No	Pretest		Post-test	
		Mean	SD	Mean	SD
Control group	58	10.79	2.285	17.64	3.270
Experimental group	56	10.88	2.413	24.48	1.954

The above data shows that the experimental group's mean score (M = 10.88, SD = 2.413) and the control group's mean score (M = 10.79, SD = 2.285) from the administered pretest were comparable. After the learning period, mean scores improved for both groups, with the experimental group showing the largest difference (13.6) from the control group (6.85). In the posttest, the experimental group's mean score (M = 24.48, SD = 1.954) was generally higher than the control group's mean score (M = 17.64, SD = 3.270), showing appreciable increase in students' academic performance in the experimental group.

Comparing pretest scores

Independent T- Test

Table 3: Pretest scores

Tests	T-test for Equality means						
	T	Df	P value	Man difference	Std error difference	95%confidence	Interval of difference
						Lower	Upper
Pretest marks	-.186	112	.853	-.082	.440	-.954	.790

The pretest score means of the two groups were compared using the independent sample T-test. It was determined that there was no statistically significant difference between the two means at a 0.05 level of significance, t (112) =-0.186, n=114, P >0.05, 95% CL for mean difference: -0.954 to -0.790. The average pretest in control group score was about -0.082 point greater than pretest in the experimental group.

Comparing post-test scores

Independent Samples T- Test

Table 4: Post-test scores

Tests	T-test for Equality means						
	T	Df	P value	Man difference	Std error difference	95%confidence	Interval of difference
						Lower	Upper
Post-test marks	-13.507	112	.000	-6.844	.507	-7.848	-5.840

The results of the independent samples-test showed that the mean score differed after treatment. The experimental group showed (M=24.48, SD=1.954) whereas treatment in control group had (M=17.64, SD=3.270) at 0.05 level significance, t (112) =-13.507, n=114, $P<0.05$, 95% CL for mean difference -7.848 to -5. 840. The average score of the post-test experimental was about -6.844 points greater than the post-test control group. Therefore, these results help us to conclude that there was a statistically significant difference between the post-test in experimental and posttest in control group scores.

Discussion of the results

According to the assessment of the academic test results reported that learners' understanding of the ideas rated to the following units was uniform at the start of the study. Additionally, the independent T-test results for the pretest scores did not show any statistical significance. However, it was determined that there was a statistically significant difference in the post-test scores for the control and experimental groups using the independent T-test indicating that the intervention, which involved low-cost materials (beetroot indicators and litmus paper) in the chemistry lessons, had a positive impact on the student's academic achievement. It was observed from comparing the two sections of the pre-and post-test that students in the experimental group performed better on the component involving Acids, Bases, and pH.

The research findings under this research question are consistent with several studies in the literature on the impact of using low-cost materials on academic achievement (Hamidu et al., 2014; Ndihokubwayo, 2016; Ndihokubwayo & Habiyaremye, 2018; Shana & Abulibdeh, 2020).

Learning becomes more permanent as a result of improvisation materials increasing learner retention rates (Peace et al., 2020). For instance, Shana and Abulibdeh (Shana & Abulibdeh, 2020) indicate that there is positive between practical and academic achievement for many students in science.

5. Conclusion and Recommendations

The findings showed that students who were taught Chemistry using low-cost materials performed better compared to those who were taught using traditional methods. The low-cost materials well designed for the study will be very beneficial to schools that lack or have insufficient resources to teach the concept.

The study recommends that using low-cost materials as a walk for standard ones when they are unavailable, especially in rural areas where resources are limited for teaching chemistry and other science disciplines at all levels.

Education authorities can also organize workshops to teach teachers in remote schools how to use improvised educational materials. In addition to this, the researcher suggests that schools that train teachers include the use of improvisation of beetroot and litmus paper for teaching and learning the concept of Acids, Bases and pH in their curriculum.

To generate broad assumptions from the results, it is also advised to conduct future studies on the idea considering a larger population.

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