The Portable Laboratory in Learning Chemistry

Elena Urquizo -Cruz, Carmen Varguillas, Narcisa Sanchez -Salcán, Carmen Viviana Basantes Vaca

Faculty of Education Sciences, Humanities and Technologies, Pedagogy of Experimental Sciences, Chemistry and Biology, National University of Chimborazo, Riobamba, Ecuador
Email: eurquizo@unach.edu.ec

Abstract

Learning experimental sciences, especially chemistry, involves both theoretical and experimental components. Laboratory experimentation has become an ideal place to link theory and practice. Educational institutions, especially those located in rural areas, mostly lack laboratories and resources to create an environment that links theory with practice; therefore, the design and implementation of a Portable Laboratory as a didactic resource is essential. The objective of the present research was to design and implement a Portable Laboratory with a user's guide that includes experimental activities and evaluate the incidence of its use in the learning of students of the second year of General Unified High School of the Milton Reyes Educational Unit in the period September 2022 - July 2023. The research was quasi-experimental because of its applied and descriptive level. The population consisted of 48 students, where parallel "A" was intentionally selected as the control group and parallel "B" as the experimental group. At the end of the research, it was determined that the Portable Laboratory constituted an important resource for the learning of Chemistry in the students who formed the experimental group; therefore, the implementation of the Portable Laboratory has a positive influence evidenced in the academic performance.

Keywords: Learning, Portable Laboratory, Chemistry, Didactic Resource, Academic Performance.

1. Introduction

The learning of chemistry implies reflection and in-depth analysis of experimental activities that lead to linking theory with practice, being a progressive, dynamic and transforming process that generates successive and uninterrupted changes in the student's cognitive activity. In general, experimental activities are educational actions that promote experiences in a specific context, carried out by the student and/or the teacher in a cooperative way, using materials, laboratory reagents and materials from their environment, oriented to articulate theory and practice in the teaching-learning process, where the verification of their theoretical foundations, observation and interpretation of chemical principles, are vital for the logical and interpretative reasoning of this science.

The teaching-learning process of chemistry is therefore related to the development of theories and experiments, the latter being of great importance for students since it allows them to apply theoretical concepts through practice (Vizcarra & Vizcarra, 2021).

The pedagogical problems related to the development of experimental activities in our country are mainly due to the fact that teachers focus their teaching on the transfer of theoretical knowledge, where experimentation is relegated and reduced to illustrative actions of theoretical knowledge, due to multiple reasons such as: lack of infrastructure and laboratory technicians, lack of resources, materials, reagents, as well as few hours for teaching the subject. This situation is observed as a reality in our country, which has been aggravated by the effects of the Covid-19 pandemic (Saltos & Ramos, 2023).

In the city of Riobamba, in the rural area, the Milton Reyes Educational Unit does not have laboratories, nor the necessary resources for the development of experimental activities of the different topics addressed theoretically in the subject of Chemistry, corresponding to the first year of the General Unified Baccalaureate, still prevails an expository style, with the absence of activities oriented to verify what happens; and activities of the predict-observe-explain-reflect type, with little emphasis on investigative activities, so that the student is limited only to what is explained in class by the teacher. There is no space that allows the student to face and solve problems, verify, investigate and apply theoretical knowledge. Therefore, it is necessary to look for strategies that allow the student to achieve the learning of the subject (Urquizo, E. & Fiallos, M. 2017). Therefore, it is necessary that teachers apply a variety of teaching strategies, as well as the use of appropriate teaching resources, to achieve the skills with performance criteria established by the Ministry of Education of Ecuador and allow students to acquire the scientific knowledge of chemistry in a critical and reflective manner.

Experimental activities contribute to the education of students not only at the cognitive level, but also at the formative and axiological level, allowing them to develop scientific and cognitive skills that include observation, criticality, reflection, interdisciplinarity of natural phenomena, for verification and refutation (Urquizo, E., Orrego M., & Fiallos M., 2022).

The use of portable laboratories provides this type of tools, playing a fundamental role in the development of students' cognitive skills and constituting an effective way to improve their learning system (Hernández et al., 2022). These experimental activities reinforce the theoretical knowledge acquired, as they stimulate the ability to solve problems and understand the phenomena that occur around them (Arroba & Acurio, 2021).

The use of a portable laboratory in the learning of chemistry generates a series of advantages and opportunities for students to experience in a practical and direct way what is related to chemical concepts, improving their skills in real situations (Fuenmayor & Morales, 2022). In addition, this type of tools allows the development of autonomous work and critical thinking, where students can generate their own essays, briefly summarize the results and draw their own conclusions. In this way, active and participatory work is guaranteed in the teaching-learning process, instead of just following predefined instructions (Martínez et al., 2017).

The present investigation consisted of the implementation of a portable laboratory (LP) to see its incidence in the teaching-learning process of chemistry with students of the second year of the General Unified High School of the Milton Reyes Educational Unit.

Learning in the educational environment establishes a change in thinking or cognitive processes, something that is not visible but can be evaluated. In this sense, understanding is based on the previous acquisition of knowledge and is built on established ideas about the functioning of the entire universe, and it is deeper when the learner is able to explain and apply what he/she has learned in future situations. Within the learning process, chemistry, as an experimental science, has as its main purpose the development of the student's scientific thinking, facilitating the understanding of the theoretical bases, the relationships between everyday events and the causes or effects of all the phenomena that occur in daily life; questioning the knowledge of the elementary foundations of nature. Therefore, this science must be approached from the experimental practice in order to understand its theoretical essence. Therefore, it is recommended to consider the following in the development of the teaching-learning process of this science.

Contextualization, starting from real situations to show how chemistry is present in their environment, such as in the kitchen, medicine, technology, cleaning industry, food, among others; this makes it possible to establish a link between chemical concepts and the daily lives of students, thus generating interest and relevance in learning.

A logical and progressive sequence of content, starting with simpler concepts and progressing to more complex topics. This will allow students to build a solid knowledge base and better understand more advanced concepts.

Encourage the development of hands-on experiences, such as experiments, demonstrations, and projects, so that students can observe and manipulate chemical substances, materials, and equipment, which will allow them to understand the concepts in a concrete way and develop scientific thinking skills.

Encourage teamwork and collaboration among students. Chemistry can be a challenging subject, and group work gives them the opportunity to discuss ideas, solve problems together, learn from their peers, foster collaborative learning that promotes the development of social and communication skills, and promote an inclusive and respectful classroom environment that ensures that all students have the opportunity to participate and learn in meaningful ways.

Use technology tools and resources that can help visualize abstract concepts to facilitate student understanding, such as experiment kits, portable labs, interactive simulations, instructional videos, mobile applications, and online resources.

Similarly, De Morán, quoted by Urquizo (2020), mentions that

To educate it is necessary that students possess or develop attitudes that favor effective learning, through a deep understanding of the contents, their relationships and applications in daily life;

for which it is necessary to promote a positive and proactive attitude in the study of sciences, especially chemistry, encouraging a direct participation of students in the construction, selection and application of this (p.111).

The teaching-learning process of chemistry is not easy, so it is necessary that teachers use the laboratory as a didactic resource for the teaching-educational process to achieve the planned learning results, and this experimental activity confronts with the reality of the phenomena studied, leading to the appropriation of scientific knowledge in a critical and reflective manner (Urquizo, Varguillas). (Urquizo, Varguillas & Sánchez, 2023), for this purpose, the implementation of a Portable Laboratory as a didactic resource that contributes to the learning of this subject is proposed in several investigations.

Use of the Portable Laboratory in the Learning of Chemistry

Faced with the obvious problem of the scarcity of experiments in the process of teaching and learning chemistry, several researches mention the use of resources such as Portable Laboratories (LP), which look like suitcases and contain equipment, materials and supplies to develop experimental activities in different environments.

The LP also contain guides with orientations on different experimental activities, use of materials and chemical substances, which usually contain a minimum quantity that allows experiments to be carried out (Santos, 2020). The implementation of the LP in the teaching and learning process of chemistry has the following advantages

- It gives students free access to materials, reagents, and equipment even if the educational institution does not have a physical laboratory. The basic materials it contains are test tubes, flasks, beakers, pipettes, thermometers, balances and stirrers, which are necessary to carry out basic chemistry experiments.

- Flexibility, since it allows the development of experiments in different environments, increasing creativity and adaptability according to the educational context.

- The built-in level of safety ensures good acceptance, minimizing the risk associated with handling chemicals.

- It allows students to make significant savings in time and resources, guaranteeing the learning of chemistry in an attractive and motivating way (Góngora & Santana, 2021).

- Students could apply theoretical concepts through direct experimentation, allowing them to observe, measure and analyze all the phenomena inherent in chemical processes. Students develop the ability to detect the presence of chemical substances and common processes, thus stimulating curiosity in the study of chemistry as a science.

- Promotes the development of fundamental scientific skills such as observation, hypothesis formulation, experimental design, data collection, data analysis, and communication of results.

- They allow working in small groups, which promotes collaborative learning and problem solving thanks to the exchange of ideas, discussion of results, and construction of knowledge;

they offer the possibility of adapting experiments and practices in middle and high school (Cevallos et al., 2018; Rodríguez et al., 2014; Vizcarra & Vizcarra, 2021). Allow students to seek solutions and explanations based on scientific evidence.

In the research conducted by Fuenmayor & Morales, (2022), highlights several benefits associated with the use of portable laboratories in the learning of chemistry. In this way, portable laboratories have become a useful tool for students to carry out their experiments in a practical and orderly manner; providing an opportunity to explore and apply concepts within the field of chemistry. In addition, portable labs encourage student participation, which promotes critical thinking in problem solving.

The use of the LP motivates students to understand the relevance of chemistry in everyday life; performing hands-on experiments in familiar environments such as the classroom. It allows chemical concepts and principles to be related to real situations and practical problems. In this way, the link between theory and practice is strengthened, helping students to appreciate the importance of the subject in different fields such as engineering, medicine, food and environmental protection (Carchipulla & Guevara, 2022; Sagó et al., 2019).

2. Methods and Instruments

Research Design

The research was carried out in the Milton Reyes Educational Unit in the city of Riobamba, located in the province of Chimborazo, with students in the second year of the Unified General High School. The research design was quasi-experimental, where Parallel B was intentionally selected as the experimental group and Parallel A as the control group, considered in a natural and intact way, since only the master class was carried out and the LP with its corresponding experimental activities was not implemented. The development of the classes in both parallels was carried out in an equitable way, that is, with the same hours and topics established in the approved annual plan. Therefore, in each of the groups of students, the grades obtained in the tests (pre and post) were taken into account, which allowed a statistical analysis of the incidence on learning and attitude towards the subject of chemistry.Types of research

Bibliographic research

Information was collected from books, scientific journals, articles, master's theses, bachelor's theses, among others (related to the problem). These allowed the development of the theoretical framework and, at the same time, to consider relevant information for the elaboration of the LP and the User's Guide, with the description and experimental activities on the selected topics.

Field research

The proposed problem was developed directly in the Milton Reyes Educational Unit, with the students of the second year of the Unified General High School distributed in parallel "A" and "B", adapting to the 2 classrooms that the educational institution has to carry out the research.

Level of research

Applied

The LP was developed with its application guides and used for the development of the Chemistry classes with the experimental group, in such a way that it was possible to determine the incidence of its implementation in learning, considering the annual plan of the said subject for the second year of the Unified General High School.

Analytical Methods

Method of analysis - Synthesis

It allowed the structuring of the theoretical part, thus providing some specific knowledge for the support and scientificity of the implementation of the LP, for the learning of chemistry, facilitating the application of procedures to meet the objectives set.

Deductive method

The research problem has been analyzed in a particular way to argue the usefulness of LP as an experimental didactic resource for learning chemistry. Deductive, since conclusions will be drawn based on the application of LP as an experimental didactic resource and its incidence in the learning of chemistry.

Population

The population consisted of 48 students of the second year of the Unified General High School of the Milton Reyes Educational Unit, and they attended normally in the period March - July 2023. Parallel A was purposively selected as the control group, while Parallel B with 25 students was selected as the experimental group.

Technique and instrument

A knowledge test (pre and post) with 10 questions on each of the topics addressed within the study units was developed, with the aim of determining academic performance; and a survey to collect information on the degree of acceptance of each student with the implementation of the LP during the chemistry class.

To measure the academic performance, both the pre- and post-tests were structured with specific multiple-choice closed questions for easy understanding, which made it possible to determine the academic performance of the students, data to be used for the appropriate statistical treatment using the R study software.

The survey used a questionnaire consisting of 5 questions with a Likert scale evaluation (strongly agree, agree, indifferent, disagree and strongly disagree), which made it possible to know the degree of acceptance and use of the LP by the students of the experimental group (parallel B), which was tabulated for the corresponding analysis.

Description of the development of the LP

After analyzing the objectives and guidelines established by the Ministry of Education for the subject of Chemistry in the second year of the Unified General High School, as well as the student context, we proceeded to develop the LP with the corresponding user's guide.

The LP has the appearance of a travel case, made of pine wood, since it has good indexes in resistance, contraction and flexion, which allows it to have greater durability; with a height of 78 centimeters, 42 centimeters wide and depth of 31 centimeters.

The LP is equipped with a digital scale, a first aid kit (alcohol, cotton and gauze) and biosafety equipment (goggles, masks and vinyl gloves), materials, reagents and the corresponding guide of description, care, use, location of its components and 10 experimental activities.

The materials that make up the LP are 10 test tubes, 2 Pyrex test tubes with lids, 3 beakers of 50 milliliters (mL), 3 beakers of 100 mL, 3 watch glasses, 2 stirring rods, 1 test tube of 100 mL, 1 volumetric flask of 100 mL, 1 alcohol lamp, 1 dropper, 1 glass container of 100 mL, 1 porcelain mortar and pestle, 1 spatula, 1 250 mL trough, 1 plastic funnel, 2 plastic racks, 1 plastic 1 mL pipette, 10 small plastic beakers, 2 plastic teaspoons, 1 cleaning brush, 10 rubber stoppers, and 1 digital balance.

The reagents included in the LP are Sodium chloride, sucrose, 5% acetic acid, sodium hydroxide, ethanol (70%), ascorbic acid, hydrogen peroxide, magnesium hydroxide, liquid soap, purple cabbage extract, sodium bicarbonate, copper(II) sulfate, ferrous sulfate, aluminum foil, pH strips, phenolphthalein, and distilled water. Each reagent has an attached label that includes pictograms from the Globally Harmonized System and the National Fire Protection Association (NFPA) safety rhombus.

The experimental guides were based on the guidelines established by the Ecuadorian Ministry of Education and the annual planning of the subject of Chemistry for the second year of the General Unified High School, approved by the Milton Reyes Educational Unit, considering the following units or topics.

UNIT II: Aqueous solutions and their reactions

- Limiting and excess reagents

- Precipitation reactions

- Oxidation-reduction reactions

- Electrolysis of water

LESSON III: Solutions

- Types of solutions (dilute, concentrated, saturated, and supersaturated).

- Physical units of concentration: Percent by mass (%m/m) and percent by volume (%m/v).

- Chemical concentration units: Molarity and molality.

- Factors influencing rate of reaction: -Temperature -Concentration -Physical state and degree of partitioning.

LESSON VI: Acids and Bases

- Catalysts

- pH

- Properties of Acids and Bases

- Acid-base indicators.

Each lab guide is structured with Informative Data, Topic, Problem, Objective, Skill with Performance Criteria, Introduction to the Topic, Materials and Reagents, Procedure and Analysis of Results. The following link allows you to visualize the designed kit and the corresponding instructions.

https://drive.google.com/file/d/1JOZfgbJWMgUDcUDNxBDvvs9XjzDKINWA/view?usp=sharing

3. Results and Discussion of the LP Application

The LP was implemented by developing 5 experimental guides with the students of the experimental group. The pretest and posttest were applied to both the control and experimental groups. The results of the pre-test and post-test were statistically compared using R estudio software and the following results were obtained.

Figure 1 shows the level of knowledge of both the control and experimental groups on the topics covered in the pre-test. As can be seen in Figure 1, three students in the control group did not reach the NAAR, which corresponds to 100%. On the other hand, 15 students corresponding to 43% of the control group are close to reaching the required learning (PAAR), and for the experimental group 20 students corresponding to 57%. Finally, 5 students reach the required learning, which corresponds to 50% for both the control and experimental groups. As shown by the results obtained, the difference between each of the learning levels is minimal, so it can be said that both groups are in the same conditions to receive the experimental treatment.

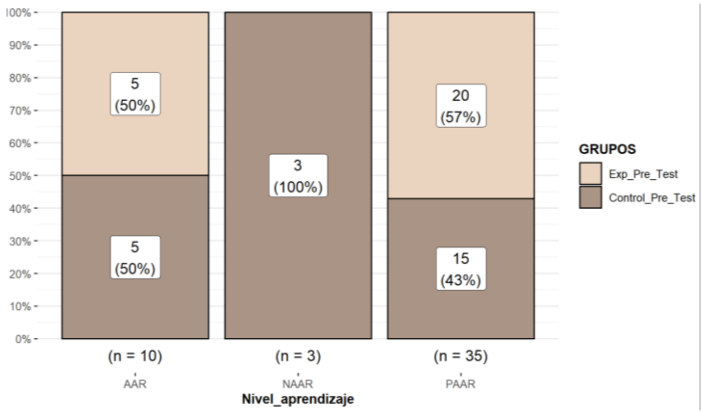

Figure 1. Level of chemistry learning between the control and experimental groups (pre-test).

On the other hand, Figure 2 shows the level of chemistry learning achieved by the students with and without the implementation of the LP. Four students (80%) in the control group did not achieve the required learning, while one student (20%) in the experimental group did not achieve the required learning (NAAR). Also, 18 students (51%) of the control group are close to reaching the required learning (PAAR) and for the experimental group 17 students (49%). Finally, only one student (12%) of the control group reaches the required learning (AAR), while for the experimental group 7 students (88%); this indicates that there is a learning difference between both control and experimental groups.

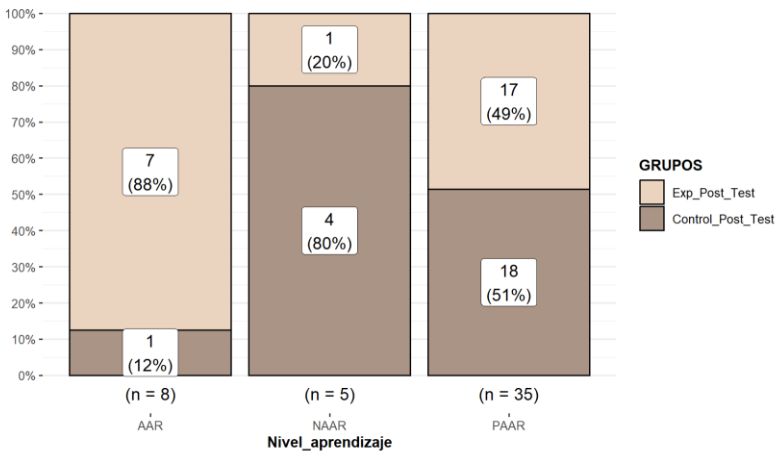

Figure 2. Level of Learning of Chemistry of the Control and Experimental Groups (Post Test)

Figure 3 shows the descriptive statistics of the control and experimental groups (post-test); regarding the control group, the minimum grade obtained is 3.5 and the maximum grade is 7.3, while the mean value of grades is 4.957. On the other hand, in the experimental group, the minimum score is 3.8 and the maximum score is 8.2; the mean score is 6.292, which shows a learning difference between the mean scores.

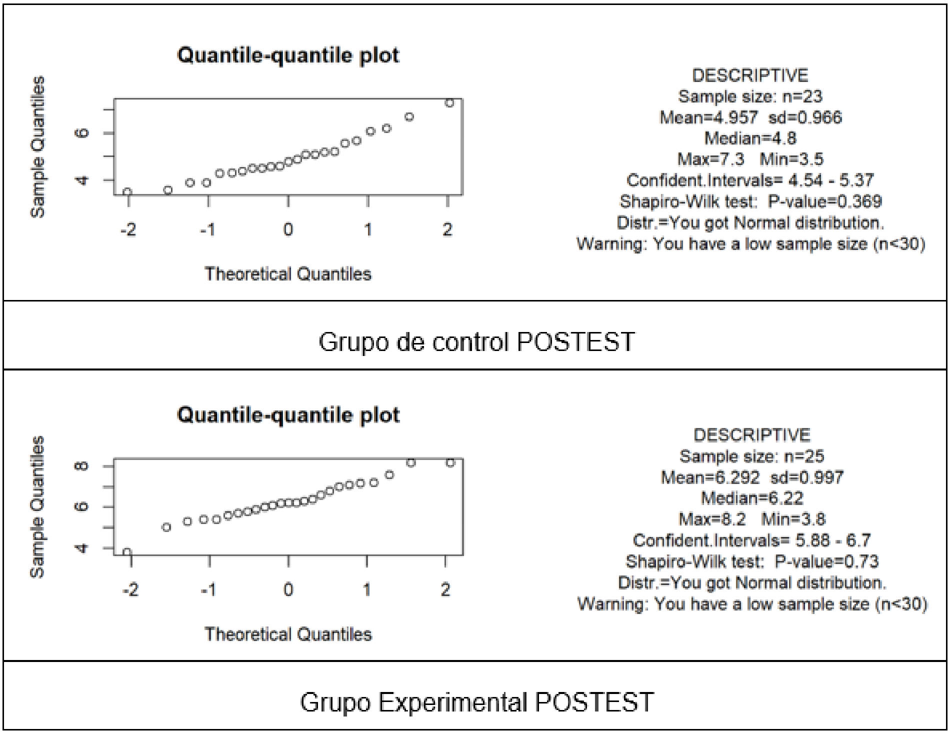

Figure 3. Normality test between control and experimental groups (post-test) in the R study software.

Similarly, the normality test of the data between the control and experimental groups post-test is presented, which was performed using the Shapiro-Willk test because it is applicable to samples smaller than 50. The p-value of the Shapiro-Willk test in the control group is 0.369 and in the experimental group 0.73, these values are greater than the significance level (0.05), so the data come from normal distributions in both cases. Also, in the quantile-quantile plot, the data tend to follow a straight line, which shows that the data come from a normal distribution.

Given that the data obtained follow a normal distribution, it was decided to select the parametric t-Student test with a two-tailed "p" value and a significance level of $\alpha = 0.05$, for which the following hypotheses were proposed

Ho: The implementation of a portable laboratory does not contribute to the achievement of chemistry learning in students of the second year of the General Unified Baccalaureate of the Milton Reyes Educational Unit, enrolled in the period September 2022 - July 2023.

H1: The implementation of a portable laboratory contributes to the achievement of chemistry learning in students of the Second Year of the General Unified Baccalaureate of the Milton Reyes Educational Unit, enrolled in the period September 2022 - July 2023.

Figure 4 shows the difference in the mean scores between the control and experimental groups (post-test) with and without the implementation of the LP, the difference in the mean scores is 1.335, with a confidence interval (CI) between 0.763 and 1.906 at 95%, these values are above the value of 0, which means that there is a statistically significant increase in the value of the result. In addition, to verify if the results obtained are statistically significant, we must look at the p-value or Sig, in this case a value of 1x10-6 was obtained. Since this value is less than the significance level (0.05), the null hypothesis is rejected, and the alternative hypothesis is accepted, which states: The implementation of a Portable Laboratory contributes to achieving Chemistry learning outcomes among the students in the Second Year of the Unified General Baccalaureate at Milton Reyes Educational Unit, who are legally enrolled for the period from September 2022 to July 2023

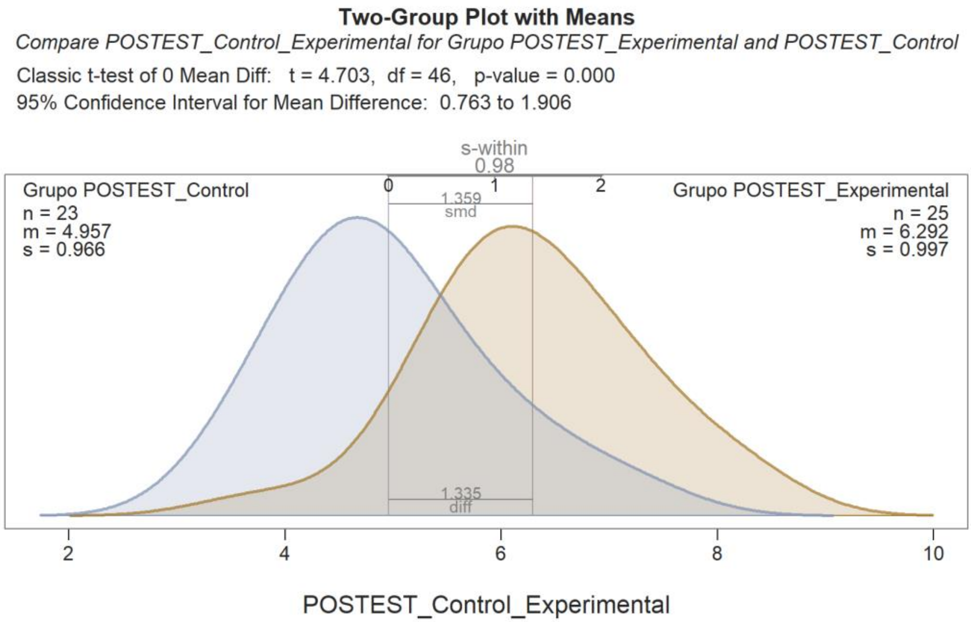

Figure 4. T-Student Hypothesis Test

Once the students in the Second Year of the Unified General Baccalaureate, parallel “B,” who formed the experimental group, had developed the classes using the Portable Laboratory for the topics in Units II, III, and VI, a survey was conducted to gather information on the attitudes and acceptance level of each student toward the use of the Portable Laboratory (PL). The survey used a Likert scale rating: Strongly agree, agree, neutral, disagree, and strongly disagree. After conducting the survey, the data was tabulated as shown in Table 1.

	Questions	Strongly agree	Agree	Neutral	Disagree	Strongly disagree	Total, respondents
1	Using the portable laboratory, students were able to easily access materials, reagents, and supplies for the development of each experimental activity planned by their instructor	23	2	0	0	0	25
2	The Portable Laboratory is an important resource that enhanced their ability to understand essential aspects of solutions, dissolutions, and acid-base theory	22	3	0	0	0	25
3	The implementation of the portable laboratory in the classroom allowed students to reflect on and analyse the theoretical aspects of Chemistry	18	7	0	0	0	25
4	The use of the Portable Laboratory with its experimental guides increased their interest and curiosity to explore essential aspects of Chemistry	17	7	1	0	0	25
5	The application of experimental activities using the portable laboratory led to active and participatory learning of Chemistry	23	2	0	0	0	25

Table 1. Frequency of students' perception with the implementation of the Portable Laboratory.

The students totally agree and agree that the experimental activities with the use of the LP were easy and practical to carry out; according to the author Rosero (2020) "The didactic guide as a pedagogical support develops different learning styles, supports academic progress and constitutes an improvement in the teaching professorship". responsible for the application of strategies that favour learning; within which the experimental activity with the Portable Laboratory is an option worth considering because it favours the learning of chemistry, improves the attitude of students towards this science and develops investigative, cognitive, procedural and axiological skills.

From the results it can be seen that most of the students fully agree and agree that the development of the activities using the LP helps to understand in an active and participative way the topics of solutions, dissolutions and acid-base theory; agreeing with the author Vizcarra (2021) who mentions that "the activities presented by the Portable Laboratory provide significant learning and encourage students to experimental learning, developing problems and experiments within the classroom".

For students, the LP represents an important resource to promote the learning of chemistry, not only theoretical, but also practical, "avoiding the teaching focus on the transfer of knowledge and where the student investigates and constructs his own learning". (Castro, 2021).

Most of the students fully agree and agree that the implementation of the LP in the classroom has brought curiosity, interest, understanding and analysis of the theoretical knowledge imparted by the teacher and has brought a number of benefits. They agree that it is an alternative resource for a rural educational institution, according to Vizcarra (2021).

The use of LP contributes to the creation of study groups and experimental work, which facilitates the learning of chemistry and therefore has a positive impact on academic performance. This coincides with the author Altamirano (2022), who mentions that "the portable laboratory uses experimental activities that, when applied within the learning process, establish relationships between facts and generate questions about why they occur". This gives way to experimental verification, the exploration of scientific knowledge, the development of observations, the recording of data, analysis and conclusions that allow students to solve problems in their environment.

In the case of the second-year high school students of the Milton Reyes Educational Unit, the implementation of the LP in the development of the lessons strengthened their theoretical knowledge and their motivation to study different topics of the subject. Each activity promoted an active, participatory, and individualized teaching and learning process in which a critical and reflective spirit was valued in each experimental activity.

In general, a positive impact on the students' learning and development of scientific skills is appreciated, and despite their economic limitations, the students show progress.

4. Conclusions

The LP allowed the development of Chemistry classes by applying experimentation on the topics of solutions, dissolutions and acid-base theory, allowing students to use materials, reagents and inputs for the development of experimental activities, in a dynamic way according to the context of the Milton Reyes Educational Unit, allowing them to build their own knowledge from their own experience using the scientific method.

The teaching-learning process through the implementation of the LP turned out to be favorable, observing a significant difference in the learning and performance of the experimental group. This difference was evidenced after the evaluation made to the students before and after the use of LP when answering the Pre Test and Post Test.

The implementation of LP as a resource within the classroom influenced the learning of Chemistry, this was confirmed through the hypothesis test with the experimental group; where the p-value of 1x10-6 was less than the significance level, there being sufficient evidence to reject the null hypothesis, demonstrating that the implementation of a LP contributes to the achievement of learning and therefore in the increase of academic performance.

The evaluation issued by the students of the experimental group regarding the implementation of the LP in the classroom, corroborates that it is a resource that favors the construction of knowledge, which leads to significant learning; product of a dynamic process that facilitates the understanding and application of concepts, as well as the development of skills, attitudes and positive aptitudes towards chemistry.

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