# Model Chemlab and Phet Simulator: A Didactic Resource for Chemistry Learning in Undergraduate Students

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**Abstracts:** The objective of the research was to determine the incidence of the application of the Model Chemlab and PhET simulator as a didactic resource to improve learning achievement in the Chemistry Laboratory course in undergraduate students during the 2022 academic year. The study used a quantitative methodology with a pre-experimental experimental design. The population consisted of 257 students of the Science, Technology and Environment Studies Program (CTA) of the Faculty of Education Sciences (FCEDUC) of the National University of the Altiplano (UNA) Puno, from which a non-probabilistic sample of 14 students of the IV cycle was selected, The Model Chemlab and PhET simulators were used in the learning sessions of the Chemistry Laboratory course with the purpose of improving the students' learning achievement. Before carrying out the experiment, a pre-test was administered, and after using the simulators, a post-test was conducted to determine the impact of the application of the simulators on the study variables. The results showed a significant improvement, with a t-value of 17.393 and a significance level of ρ=0.000 these findings indicate that the students achieved an efficient use and management of the simulators, which favored their learning in the Chemistry Laboratory course.

**Keywords:** Learning, Strategy, Virtual laboratory, Simulator.

## 1. INTRODUCTION

Due to the Covid-19 pandemic that affected the world, significant changes occurred in the teaching-learning process. Face-to-face education had to be adapted to a remote modality, following the guidelines established by the institution of [1]. This transition to remote education had a particular impact on Chemistry courses, especially with regard to laboratory work, since it was not possible to carry out experiments with real instruments and reagents, to solve this situation, the need arose to resort to alternative resources, such as interactive simulators, including Model ChemLab, PhET and other simulators, It is also important to highlight that, at present, the new generations are considered digital natives, since they are familiar with information and communication technologies (ICT), so in the field of education, ICT has been applied, including simulators, as a way to capitalize to improve the educational process [2].

In this sense, digital technologies are highly revolutionary, as creators are constantly improving them to achieve a more immersive experience, so that students can adapt to the virtual world, which is part of the learning process [3] For this reason, it is essential to apply alternative methodologies in science teaching, which lead students to explore, using ICT for learning and achieve a broad understanding with complex knowledge, promoting interest in science [4]. On the other hand, the importance of the use of virtual laboratories through an ICT system to perform planned experiments, through laboratory practice guides and develop activities in the laboratory using materials, instruments and reagents that are displayed in interactive simulators that are very dynamic, with images, animations and obtain results to achieve the proposed purposes [5].

Hence the importance in science education, it is advisable to design different virtual environments of laboratory work, digital simulations for students to learn through creativity, skills based on problematic situations and following the steps of the scientific method, from guided tours to complex practices [6,7]. From this perspective, virtual simulators are techniques used in education during the teaching and learning process in science courses to study complex phenomena in order to guarantee scientific knowledge [8]. Simulators are considered as dynamic didactic resources in the teaching of subjects due to their potential to perform complex simulations to observe reality [9].

PhET interactive simulations have been widely adopted by teachers and educational researchers due to their solid theoretical and pedagogical foundation supported by educational research, these simulations are constantly improving and meet the characteristics mentioned above [10] this simulator was founded in 2002, by Carl Wieman, Nobel Laureate, established the PhET Interactive Simulations project at the University of Colorado Boulder, this project is dedicated to developing freely accessible interactive math and science simulations, these PhET simulations are based on extensive educational research and capture the interest of students by providing an intuitive game-like environment for students to learn through active exploration and discovery [11].

That is why an alternative in teaching to perform laboratory activities are the software Model ChemLab and PhET containing dynamic and interactive simulators of virtual laboratories in chemistry that are created through software programming, and contains elements to strengthen students to develop creativity, skills and abilities by putting into practice the scientific method, also used when the physical laboratory does not have materials, instruments and reagents, being an alternative the use of these interactive simulators in science courses [12].

The application of active experimental strategies is an active learning method that stimulates students to develop competencies through interactions, using simulators in laboratory classrooms. Under this perspective, experimental chemistry is related to laboratory work, where a variety of experiments are performed [13].

## 2. MATERIEL AND METHODS

The research methodology applied was within the positivist paradigm with a quantitative approach, the type of research was experimental, with a pre-experimental design. For this purpose, a pretest and posttest were applied with a single group, prior to the experimental treatment, then the treatment was applied and finally a post-stimulus test was taken, to determine the incidence of the study variables with respect to the application of the Model ChemLab and PhET simulator as a didactic resource in the learning achievement of the Chemistry Laboratory course to observe what is the level of effect [14]. The study population consisted of 257 students of the CTA study programme, from which a non-probabilistic or intentional sample of 14 students was taken, consisting of 6 women and 8 men, to whom the Model ChemLab and PhET simulator was applied for the achievement of learning in the Chemistry Laboratory course, in the IV academic cycle, which consisted of 09 learning sessions, which consisted of virtual laboratory practices, through laboratory practice guides, in which the students have developed the competence to investigate through scientific methods to build knowledge. Also, the development of laboratory practices have been evaluated using the rubric to determine the level of learning achievement on the other hand, the pre-test and post-test were compared, with the application of the simulator Model ChemLab and PhET, the grades obtained were observed the effect of the incidence between the study variables, whose result with Student's t was t =17.393. The design is diagrammed as follows:

G M1 X M2

To test the research hypothesis, the inferential statistic of Student's t for related tests was applied, applying the normality test that determined the use of inferential statistics. For this purpose the formula is as follows:

$$t = \frac{d}{S_d \sqrt{n}}$$

**Where**
t: calculated t-statistic
d: average difference
Sd: standard deviation of differences
n: sample

## 3. RESULTS AND DISCUSSIONS

The application of the Model ChemLab and PhET simulator as a strategy for the learning achievement of the Chemistry Laboratory course was developed in 09 sessions in the pre-experimental group. Before the application a pretest was taken, to obtain information about the previous knowledge of the use of the simulator, after the end of the treatment it was evaluated with a post-test.

The purpose of the sessions was to develop the inquiry competence through scientific methods to build knowledge to improve learning achievement, through simulators, for this purpose, practice guides were elaborated, based on which the five capabilities shown in Figure 1 were developed.

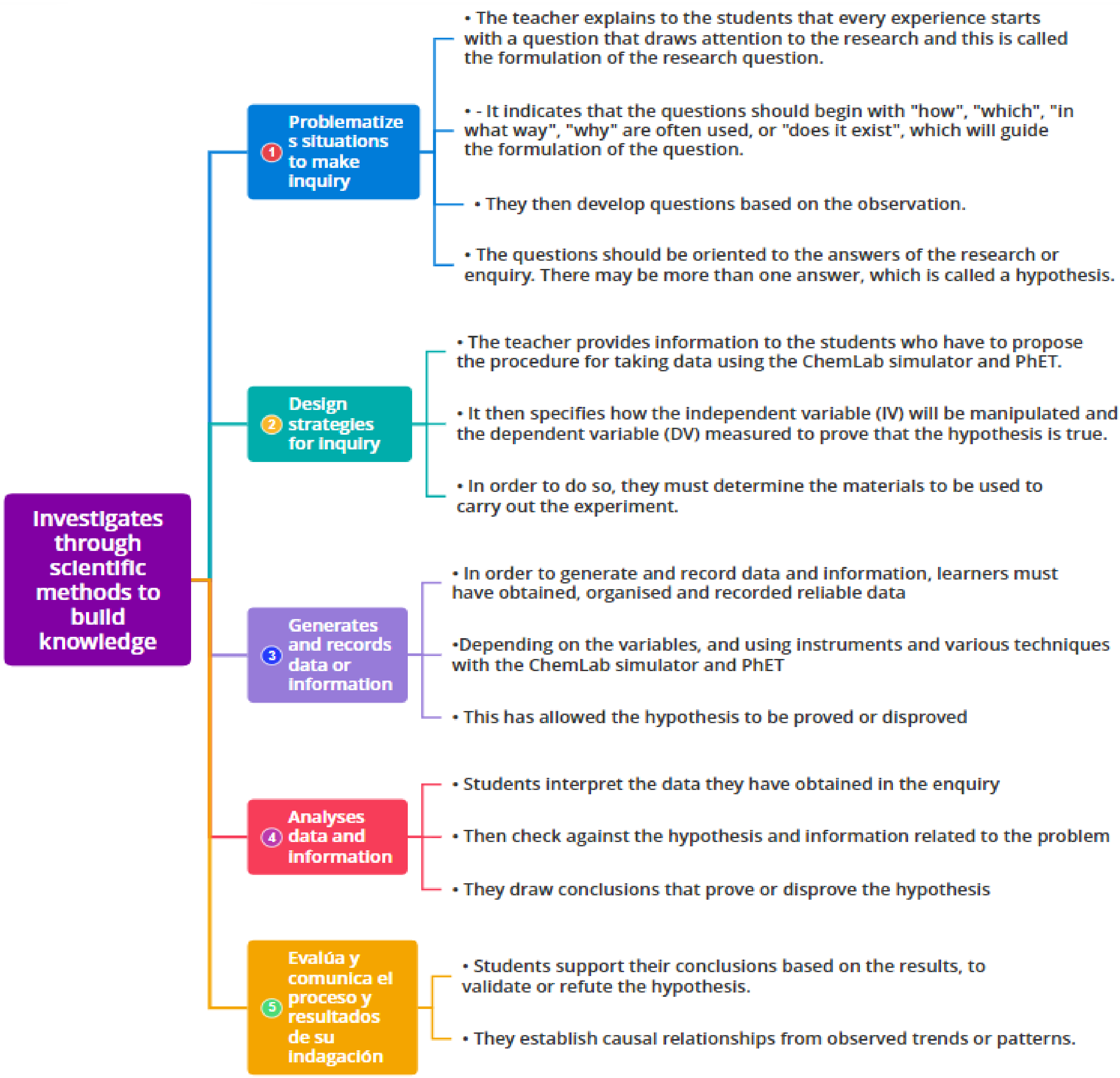



**Figure 1.** Competence development in the learning sessions with the ChemLab and PhET simulator.

The sessions developed with the Model ChemLAb and PhET simulator are shown in table 1.

**Table 1. Model ChemLab and PhET simulator application sessions**

| Session | Title of the session | Description | Modality |
|---|---|---|---|
| 1 | Determination of Acid-Base by pH Metric titration | Pre-test was applied<br>Organised into teams to assign roles.<br>The ChemLab simulator was applied, according to the session planned in the laboratory guides.<br>Students problematise situations to carry out enquiries.<br>Design strategies for enquiry.<br>Generate and record data or information<br>Analyse data and information and finally<br>Evaluate and communicate the process and results of their enquiry.<br>In the development of the session, the concentration of an acid (HCl) and a hydroxide or base (NaOH) was determined in the solution, the reaction of both reagents was carried out with the simulator, whose concentration is precisely known and is associated with the titration method, In the experiment carried out, it was observed that at the equivalence point there was an abrupt change in pH from 11,13 when the volume dropped to 29,6 ml the pH dropped sharply to 3,48 when the volume dropped to 30,1 ml, the determination curve was formed and at the end of the 50 ml volume the pH was 1,30 which was determined using the pH indicator. | Face-to-face with interactive whiteboards |
| 2 | Gravimetric analysis of chlorides | Organised into teams to assign roles.<br>The ChemLab simulator was applied, according to the session planned in the laboratory guides.<br>Students problematise situations in order to carry out enquiries.<br>Design strategies for enquiry.<br>Generate and record data or information<br>Analyse data and information and finally<br>Evaluate and communicate the process and results of their enquiry.<br>In the development of the session it was determined the formation of a silver chloride (AgCl) it is necessary the reaction of chloride ions (Cl-) with silver ions (Ag+) to recognise the reaction of the reactants Ag+ (aq)+ Cl- (aq) and the product AgCl (s) is obtained which is silver chloride, for which it has formed a solid that is observed as a precipitate in the clock moon. | Face-to-face with interactive whiteboards |
| 3 | Determination of specific heat | Organised into teams to assign roles.<br>The ChemLab simulator was applied, according to the planned session through the laboratory guides.<br>The students, under the guidance of the teacher, develop the 5 skills of the competence "investigates through scientific methods to build knowledge".<br>In the simulator experiment it is determined that the specific heat of the metal iron (Fe) is determined from the temperature change or temperature increase. In order to determine the heat produced, a calorimeter was needed. | Face-to-face with interactive whiteboards |
| 4 | Compression of a gas | Organised into teams to assign roles.<br>The ChemLab simulator was applied, according to the planned session through the laboratory guides.<br>The students, under the guidance of the teacher, develop the 5 competences of the competency "investigates through scientific methods to build knowledge".<br>The valuation table obtained in the experiment was analysed, which shows that with a gas volume of 60 ml there is no pressure in kPa, with 50 ml it was 18 kPa, at 40 ml it was 45 kPa and at 10 ml it is 350 kPa, so it is observed that the lower the volume the higher the pressure, it is concluded that for compression of a gas to occur its volume must be reduced and this will increase the pressure it exerts, also the higher the volume the lower the pressure, and the lower the volume the higher the pressure. | Face-to-face with interactive whiteboards |
| 5 | PH determination (acidic or basic) | Organised into teams to assign roles.<br>The PhET simulator was applied, according to the session planned in the laboratory guides.<br>Students have demonstrated using the PhET simulator the acidity or basicity of the following substances: drain cleaner, hand soap, blood, saliva, milk, chicken soup, coffee, orange juice, soda, vomit, battery acid and distilled water. | Face-to-face with interactive whiteboards |
| 6 | Build a molecule | Work teams were formed to assign roles.<br>The PhET simulator was applied, according to the session planned in the laboratory guides.<br>With the PhET simulator, on the main introductory page, students use the method of constructing a molecule with the elements that appear and carry out the construction of a molecule by balancing using the tools. | Face-to-face with interactive whiteboards |
| 7 | Molarity | Organised into teams to assign roles.<br>The PhET simulator was applied, according to the session planned in the laboratory guides.<br>The students used the steps of the scientific method to demonstrate molarity using the PhET simulator, determining the functions it has for the use of an experiment.<br>They concluded in the experiment that the way in which the molarity concentration bar is in the solution, since the other solutes have a higher bar and are more soluble, whereas the two least soluble solutes are potassium permanganate and potassium dichromate, of course, if we are talking about water. | Face-to-face with interactive whiteboards |
| 8 | Balancing of chemical | Organised into teams to assign roles.<br>The PhET simulator was applied, according to the session planned in the laboratory guides.<br>Students demonstrated by means of the PhET simulator the balancing of chemical | Face-to-face with interactive |

| | | | |
|---|---|---|---|
| | equation | equations. | whiteboards |
| 9 | States of matter | Organised into teams to assign roles.<br>The PhET simulator was applied, according to the session planned in the laboratory guides.<br>Students select the states of aggregation of matter, first solid, then liquid and finally gaseous.<br>Substances have higher temperature when they are in the gaseous state, while they have lower temperature when they are in the solid state.<br>Substances when heated change their volume (they expand)<br>Substances change their volume (contract) when heated.<br>Each substance has different properties in its normal state<br>Some substances react adversely to some changes of state.<br>Post-test was applied. | Face-to-face with interactive whiteboards |

The following are some evidences of the sessions developed using the model ChemLab and PhET simulators

**Session 1.** Acid-Base Determination by pH Metric Titration

**Generate and record data or information.**

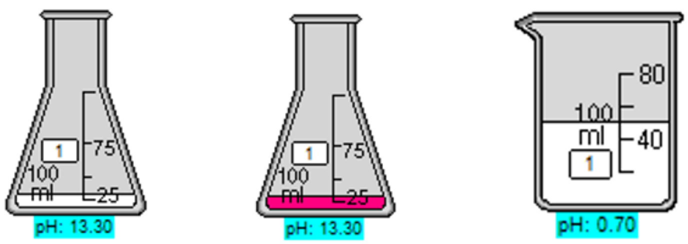



**Figure 2.** Procedure.

Figure 2 shows that the materials were selected with the Model ChemLab simulator in the 100 ml Erlenmeyer flask, 30 ml of 0.20 M sodium hydroxide (NaOH) was added to determine the pH, which was 13.30, then two drops of phenolphthalein indicator were added, which turned red currant, then in a 100 ml beaker, 50 ml 0.20 M hydrochloric acid (HCl) was added; observing that the pH was 0.70.

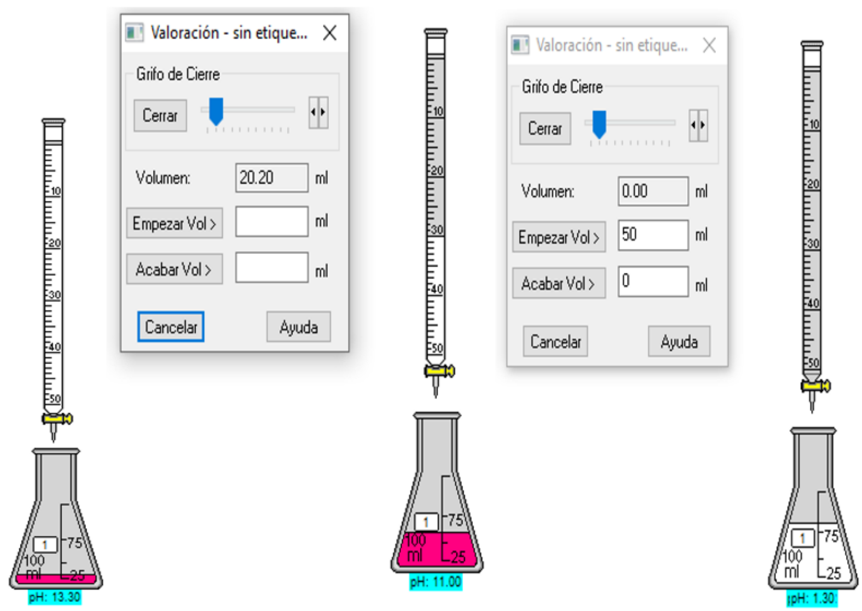



**Figure 3.** Titration of the acid-base titration experiment.

Figure 3 shows, after determining the pH of each reagent, a 50 ml graduated burette was selected, in which 50 ml of HCl was poured. Subsequently the titration was carried out on the Erlenmeyer flask containing the NaOH substance, as the HCl descends the pH was lowering until it dropped to pH 1.30 changing to colourless red currant

NaOH solution, due to the presence of HCl, which in the titration has been obtained Sodium Chloride with water. The phenolphthalein allows to determine if a solution is basic, therefore, this indicator is colourless when its pH < 8. Subsequently, with an eyedropper the solution was extracted to be poured into the beaker number 2, then the thermometer was introduced at room temperature which marked 20°C, then the Bunsen burner was selected and the temperature increase was observed and the solution began to bubble, finally the NaCl remained in the beaker and the H2O evaporated. While the pH titration was being carried out, the simulator made a graph for every second and recorded pH titration data with ml of the titrant.

**Analyses data and information**

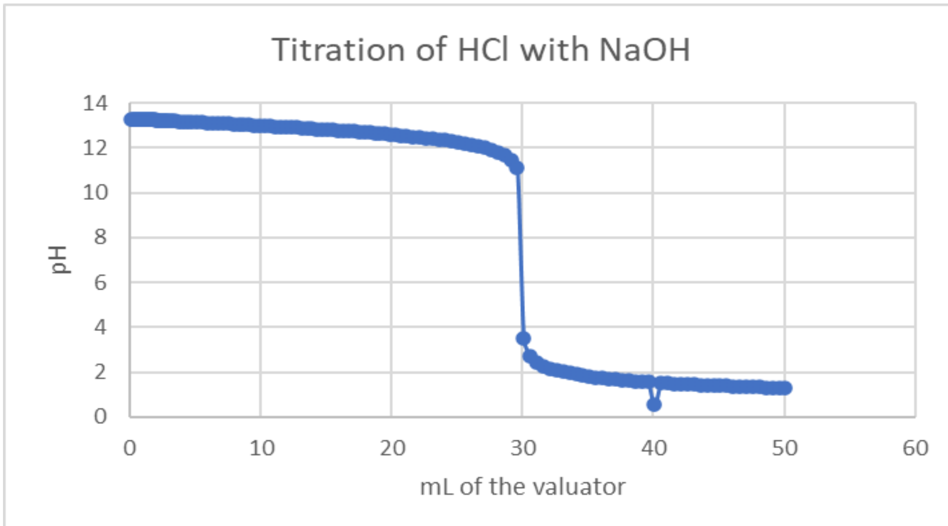



**Figure 4.** Titration of hydrochloric acid with sodium hydroxide.

In figure 4 for data analysis, it was observed that at the equivalence point there is a sharp change in pH from 11.13 when the volume drops to 29.6 ml the pH dropped sharply to 3.48 when the drop volume was 30.1 ml, formed the determination curve and at the end of the 50 ml volume the pH was 1.30 which was determined using the pH indicator.

**Session 2.** Gravimetric analysis of chlorides

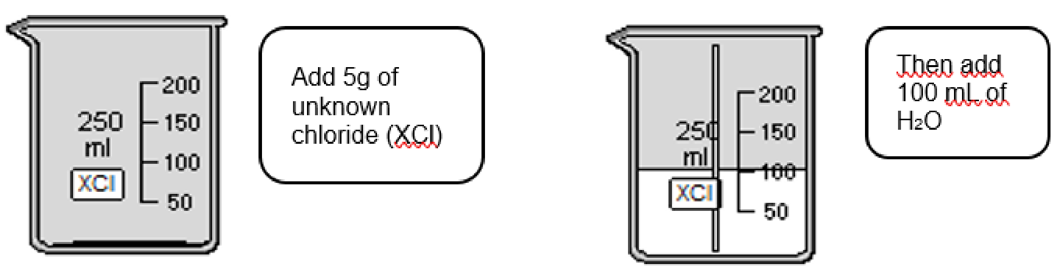



**Figure 5.** Procedure.

Figure 5 shows that with the Model ChemLab simulator application, a 250 mL beaker was selected, then the reagent 5 g of unknown chloride (XCl) was added. Subsequently, 100 mL of water was added to the beaker containing the XCl, to dissolve with the stirrer.

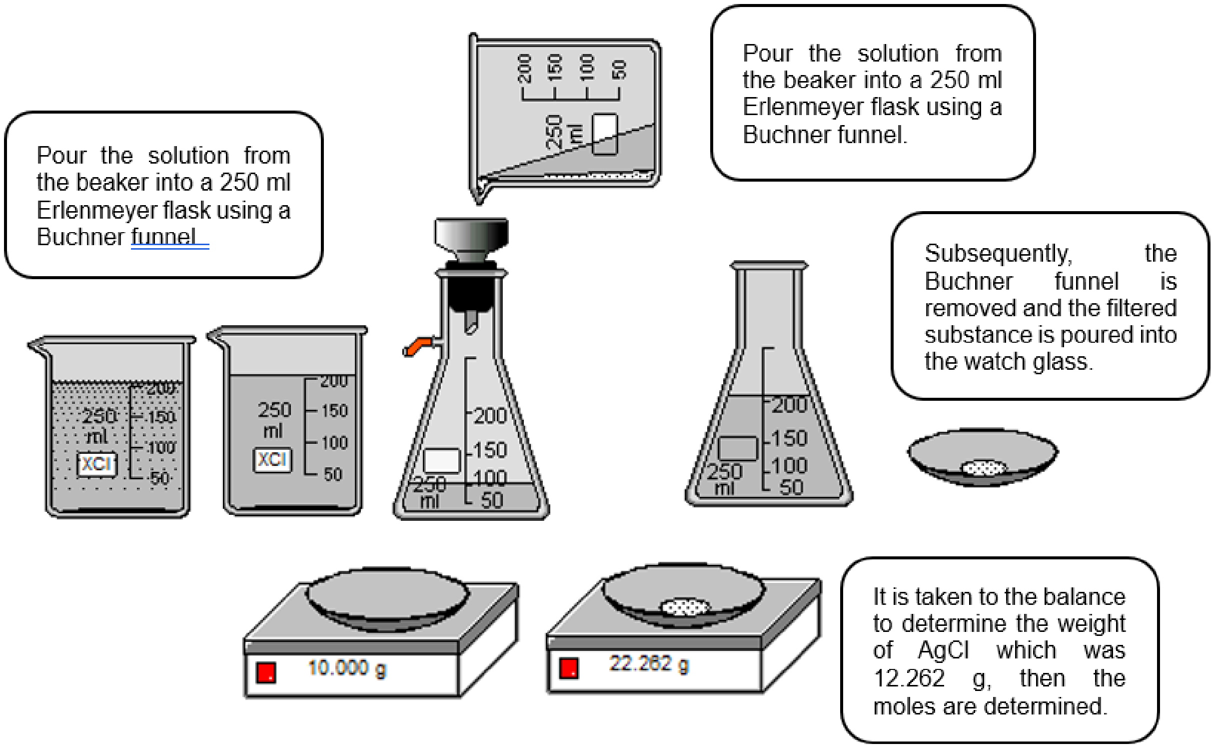



**Figure 6.** Procedure 2.

Then a 10 mL pipette was selected and 1 mL of nitric acid (HNO3) was added, then poured into the beaker containing the XCl solution. Subsequently, a 100 mL graduated cylinder was selected to add a 100 mL 0.1 M solution of silver nitrate (AgNO3), then the AgNO3 was added to the XCl solution, and a precipitate of AgCl was gradually deposited at the bottom. The completed reaction was then checked to verify the properties of the beaker, double-clicking on the beaker confirmed that the entire XCl sample (in solution) had been consumed. Subsequently, a 250 mL Erlenmeyer flask is selected and a Buchner funnel is placed in order to pour the beaker with the substances. The filter is removed from the flask by clicking on the Buchner funnel and poured into a watch glass, weighed and recorded. Finally, with the reaction of chloride ions and silver ions a silver chloride precipitate was formed. The weight of the silver chloride (AgCl) was 12.262g. Knowing its mass, we determine how many moles there are, which is 0.085558 mol. Its weight is 2.262 as the watch moon weighs 10.00g.$AgNO_3$(s) + $H_2O$ ® $Ag^+$ (aq) + $NO_3^-$ (aq).

$Ag^+$ (aq) + $Cl^-$ (aq) ® AgCl (s)

**Session 3.** Determination of specific heat

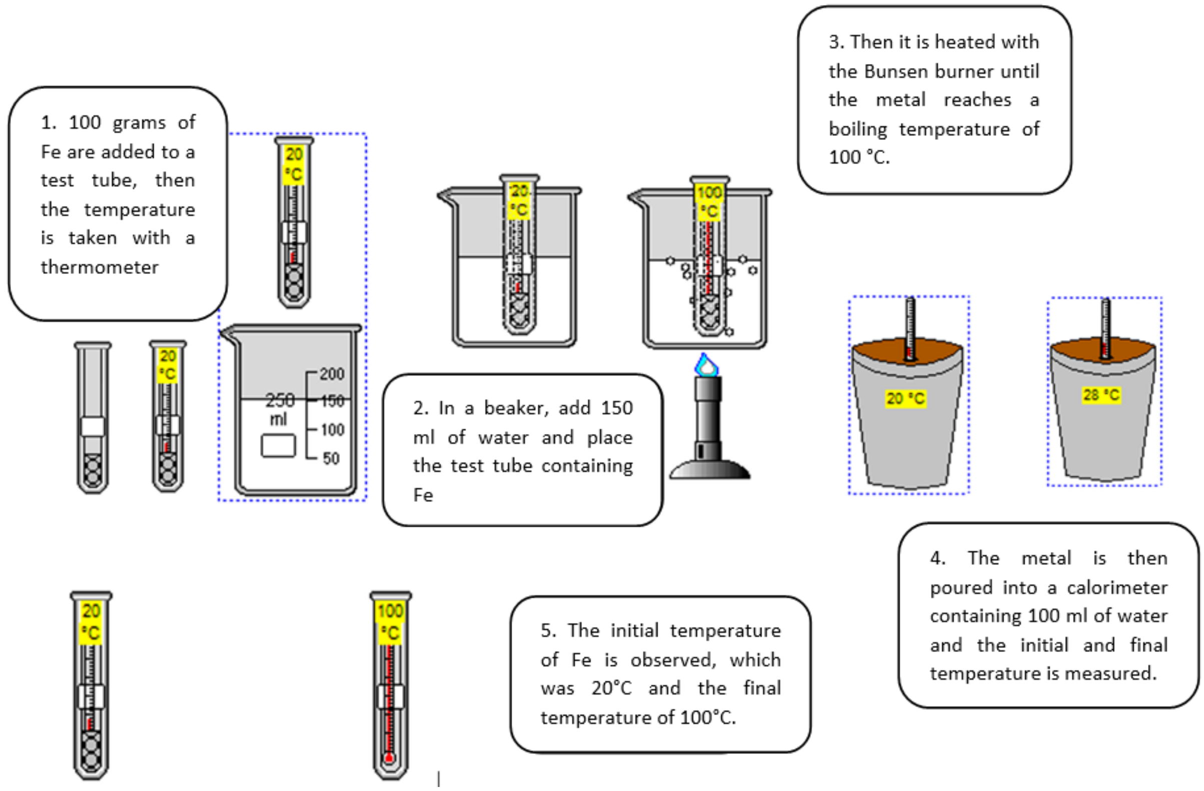



**Figure 7**. Procedure

With the ChemLab simulator, a test tube was selected, then 100 g of Fe was added and the temperature was taken with the thermometer, then 150 ml of water was added to a beaker and the test tube containing the Fe was placed in it, then a Bunsen burner was selected to heat the metal until it reached a boiling temperature of 100°C. After boiling, the metal is poured into a calorimeter containing 100 ml of water and the initial and final temperature is measured. The initial temperature of the Fe is 20°C and the final temperature is 100°C.

**Sesionn 4.** Compression of a gas

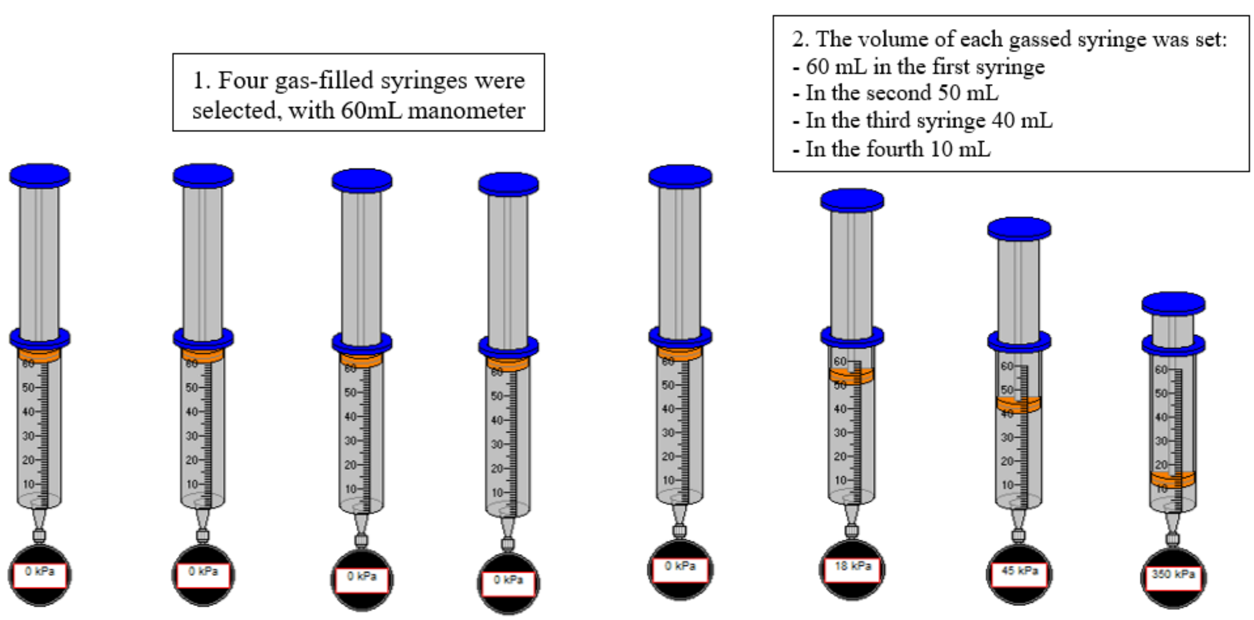



**Figure 8.** Procedure

After having carried out the experimentation with the Model ChemLab simulator regarding the compression of a gas, the following results were obtained.

**Table 3. Gas volume and pressure**

| Gas volume in mL | Pressure in kPa |
|---|---|
| 60 mL | 0 kPa |
| 50 mL | 18 kPa |
| 40 mL | 45 kPa |
| 10 mL | 350 kPa |

Table 3 shows the results of the experiment carried out with the Model ChemLab simulator, where the higher the volume of gas the lower the pressure in kPa and the lower the volume of gas, the higher the pressure in kPa. This is because, if the gas is compressed, keeping the temperature constant, the pressure increases as the volume decreases. However, if the gas is expanded at constant temperature, its pressure decreases as the volume increases [15]. So in order for a gas to be compressed there must be less volume, i.e. the pressure of a gas varies in inverse proportion to the volume.

**Session 5.** Determination of pH (acidic or basic)

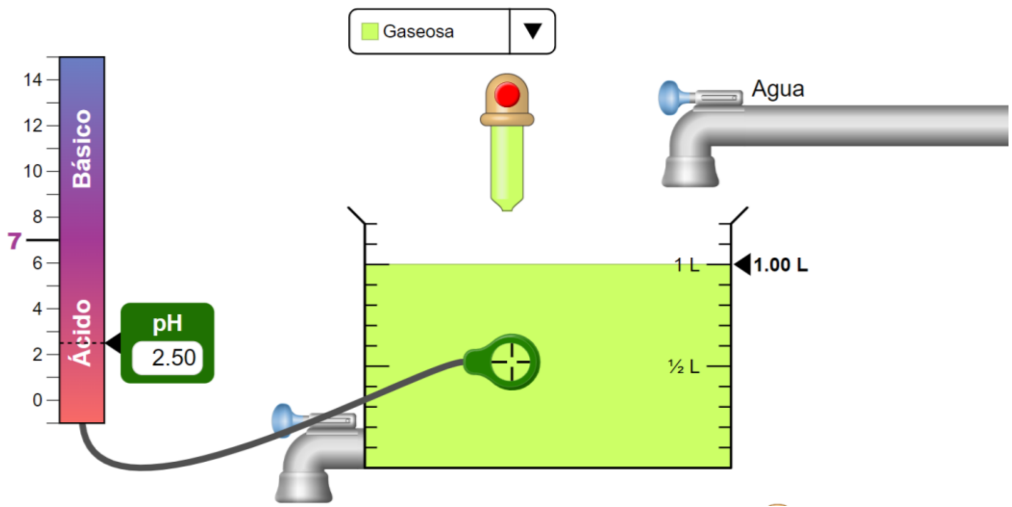



**Figure 9.** Procedure with the phET simulator

Once the procedures have been carried out for each of the solutions shown, it can be concluded that some of them are foods whose pH was acidic and others base or alkaline, and therefore have the advantage of alkalising the human body, bearing in mind that the pH of the fluids in the body should be mainly alkaline, as when these values are unbalanced, then we enter the spectrum of illness. So ideally our diet should be composed of 20 to 25% acidic foods and 75% to 80% alkaline foods as the pH of a food is one of the main factors that determine the survival and multiplication of micro-organisms during preparation, storage and distribution.

**Session 6.** Build a molecule

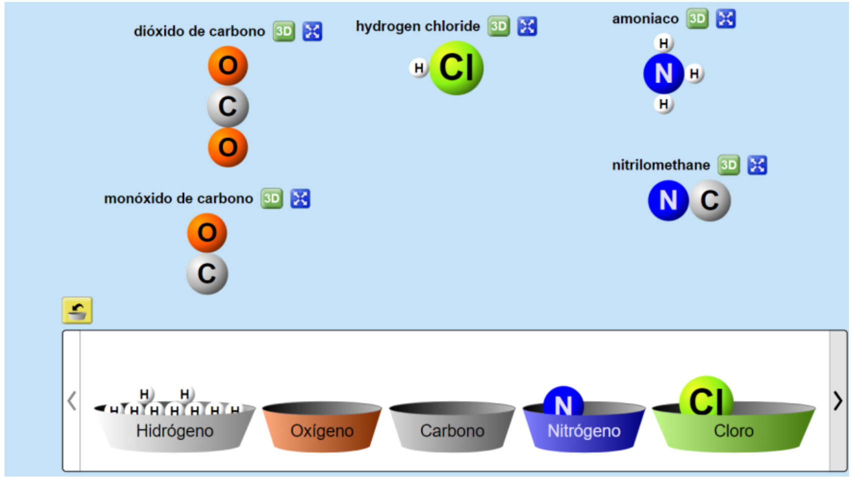



**Figure 10.** Procedure with the phET simulator

Through PhET's interactive simulations, students are placed in the virtual laboratory to build a molecule, where three windows are shown: one molecule, multiple molecules and exploration room, to form compounds between two or more atoms, either of the same element or of different elements such as water ($H_2O$), molecular oxygen ($O_2$), carbon dioxide ($CO_2$) among other compounds in this simulator presents trays of different elements to form compounds. Students experiment with combining atoms to build larger molecules.

**Session 7:** Molarity

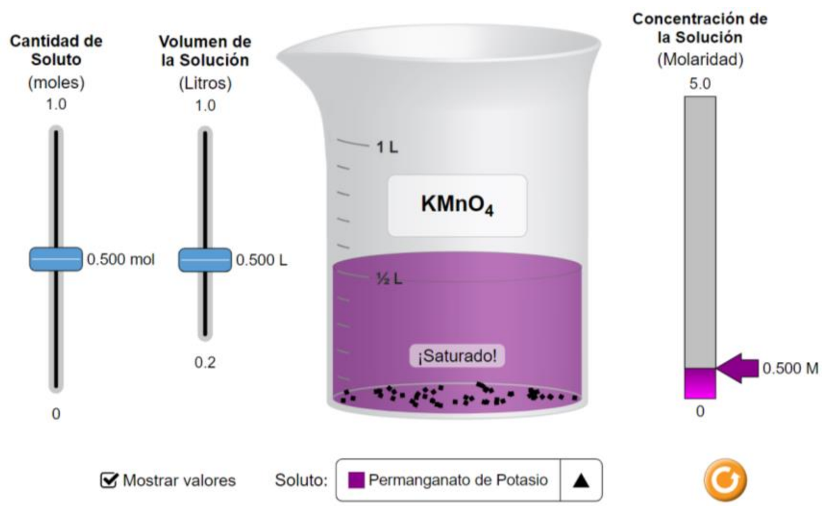



**Figure 11.** Procedure with the phET simulator

In the PhET interactive simulator regarding Molarity, where students following the steps of scientific method like describing the relationship between volume and amount of solute in a concentration, also students explain how the colour and concentration of a solution are related, on the other hand, the concentration of solutions is calculated in units of molarity, furthermore molarity is used for the calculation of dilution of solutions and finally compares the solubility limits between solutes.

**Session 8:** Balancing chemical equations

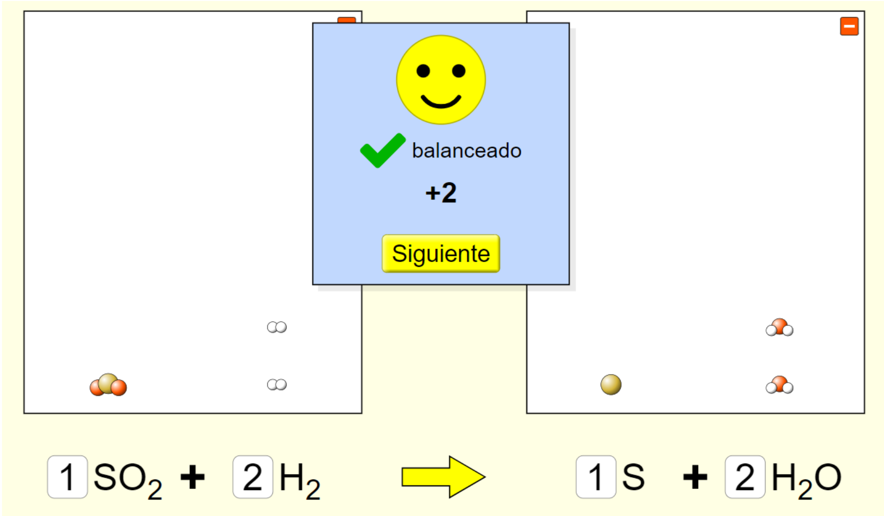



**Figure 12.** Procedure with the phET simulator.

Regarding the balancing of chemical equations with the PhET simulator, the balancing of different chemical equations was carried out, it was also recognised that the number of atoms of each element is conserved in a chemical reaction, and the difference between coefficients and subscripts in the chemical equation was also described.

**Session 9:** States of matter

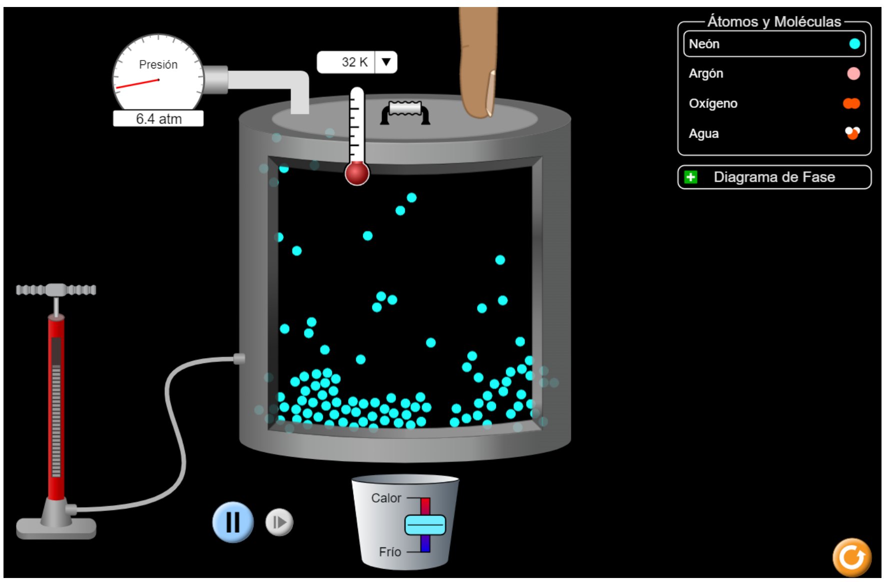



**Figure 13.** Procedure with the phET simulator.

Using PhET's interactive simulator on states of matter, students through the scientific method managed to realise how heating or cooling changes the behaviour of molecules, on the other hand, how changing the volume affects temperature, pressure and state, relate a pressure temperature diagram to the behaviour of molecules.

- Describe a molecular model for solids, liquids and gases.
- Extend this model to phase changes.
- Describe how heating or cooling changes the behaviour of molecules.
- Describe how changing volume can affect temperature, pressure and state.

- Relate a pressure-temperature diagram to the behaviour of molecules.
- Interpret interatomic potential graphs.
- Describe how the forces on atoms relate to the interaction potential.
- Describe the physical meaning of the parameters in the Lennard-Jones potential, and how this relates to the behaviour of molecules.

For the presentation of the research results, the following scale is presented:eculas.

| Qualitative scale | Quantitative scale |
|---|---|
| Insufficient | [0-10> |
| Sufficient | [0-10> |
| Good | [14-17> |
| Very good | [14-17> |

On the other hand, a pre-test and a post-test were administered to 14 IV cycle students of the CTA Study Programme of the EPES

**Table 6.** Incidence level of application of the Model ChemLab simulator as a didactic resource for chemistry laboratory learning.

| Level of learning achievement | Pretest | | Post test | |
|---|---|---|---|---|
| | fi | % | fi | % |
| Insufficient [0-10> | 3 | 21,4% | 0 | 0% |
| Sufficient [11-13> | 9 | 64,3% | 1 | 7,1% |
| Good [14-17> | 2 | 14,4% | 6 | 42,9% |
| Very good [18-20] | 0 | 0% | 7 | 50% |
| Total | 14 | 100% | 14 | 100% |

**Note.** Pretes y postest

Table 6 shows that in the pre-test 8 students (64.3 %) are in the sufficient level, i.e. they obtained marks between 11 and 13 points, followed by two students (14.4 %) who obtained marks between 14 and 17 points, which places them in the good level, and three other students (21.4 %) obtained marks between 0 and 10 points.

While the post-test shows that 7 students (50%) have obtained marks between 18-20 marks, 5 students (35.7%) have obtained marks between 14-17 marks, while two students (14.3%) have marks between 11-13 marks.

Results that are similar to [16] where they indicate that in the pretest 90% of students have obtained marks between 0 to 10 points, where it was located in the starting level, 10% of students have marks between 11 to 13 points, no student managed to obtain marks between 14 to 20 points. Likewise, in the post-test the marks after the treatment reflected the increase 43% of students obtained marks between 18 to 20 points, placing them in the level of outstanding achievement, 43% had marks between 14 to 17 points, which are in the expected achievement level and no student obtained marks between 0 to 14 points.

According to [17] the use and combination of both didactic materials such as the Model ChemLab simulator and Gogle Classroom, where it was positive because 98% of students responded that the strategy applied to develop the units was interesting, while 79% indicated that the learning was mediated through the use of both resources. Also, [18] mention that the use of software for the study of inorganic chemistry is of great importance in the development of competences in students. Also [19] in their results indicate that students have a preference for using virtual tools during the sessions, which offers better academic performance. The results show that 62% of students prefer to study the redox process through ICT tools; while 62.5% indicate that the ICT used is beneficial for the sessions, another 59% agree that ICT is more efficient than traditional sessions.

On the other hand, [12] indicates that the ChemLab simulator is a didactic, dynamic resource whose purpose is to awaken interest and motivation in students, in order to facilitate the understanding of knowledge related to concepts of scientific disciplines such as chemistry. Also [20] the research has contributed that, in the chemistry course sessions, new learning proposals were provided by applying interactive dynamics with different resources to develop curricular knowledge to improve learning. In this way developing competencies in accordance with [13] which consists of the application of experimental methodology is indispensable for developing competences in the Chemistry course, allowing the obtaining of solutions to solve experimental problems, driving students to research using the steps of the scientific method.

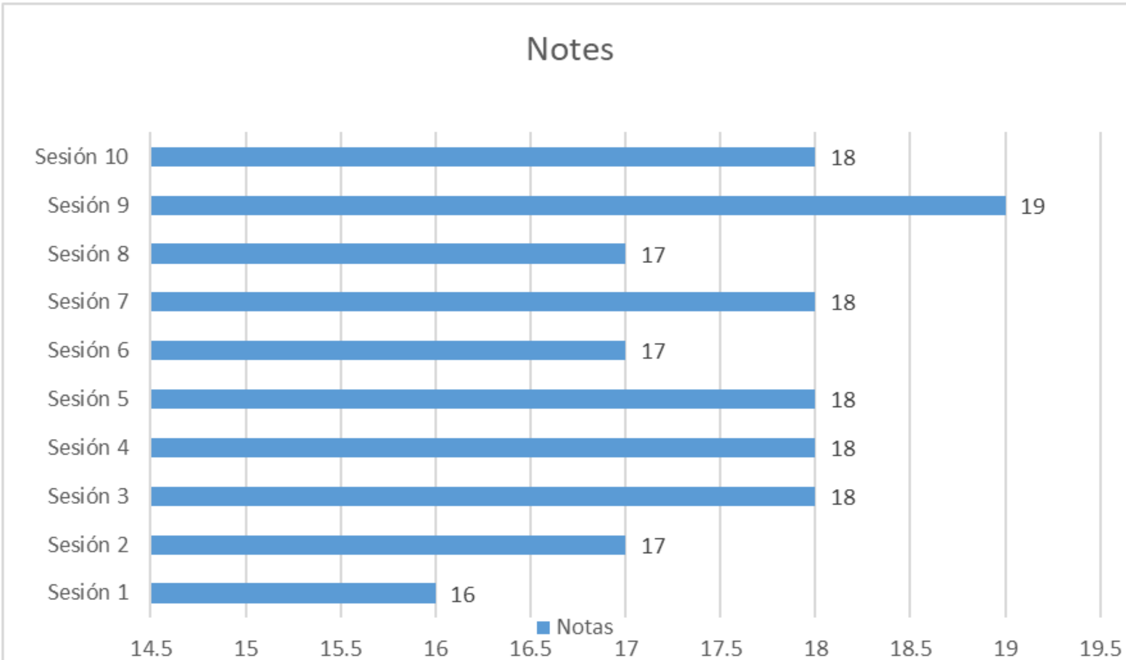



**Figure 14.** Results of the development of sessions with the application of the Model ChemLab and PhET simulator to develop the competency investigates through scientific methods to build knowledge.

Figure 14 shows that the students have developed the competence of inquiring through scientific methods to construct knowledge with the 5 capacities, for which the learning sessions were elaborated with a laboratory guide, where they were evaluated by means of a rubric with the criteria presented in table 7 below.

**Table 7. Rubric for assessing performance**

| Desempeños | At the beginning (1) | In progress (2) | Expected achievement (3) | Outstanding achievement (4) |
|---|---|---|---|---|
| Formulate the research question and hypothesise based on scientific knowledge and previous observations. | | | | |
| Develops the plan of observations or experiments and argues them using the scientific principles and the stated objectives. | | | | |
| Select materials and record data from experimentation that evidence the action of various types of variables. | | | | |
| Analyses data to interpret based on scientific knowledge | | | | |
| Formulate conclusions, argue on the basis of your results and reliable information. | | | | |

*Note.* Own elaboration

Importantly, it is important that students through science education in Secondary Education should encourage problem solving as a means of cultivating the ability to make informed decisions on the part of active citizens. However, the use of skills associated with scientific practices, such as posing researchable questions, formulating testable hypotheses, designing experiments, applying critical and logical thinking to establish relationships between variables, and communicating arguments supported by evidence, can be challenging for students [21]. On the other hand the result is similar to [22]. The methods for teaching these skills are mentioned, as well as the fundamental principles for creating a system of tasks focused on the development of each specific skill and block that we have identified.

**Table 7.** Shapiro-Wilk normality test

| | Shapiro-Wilk | | |
|---|---|---|---|
| | **Statistician** | **gl** | **Sig.** |
| Pre test | ,916 | 14 | ,192 |
| Post test | ,915 | 14 | ,184 |
| a. Lilliefors' significance correction | | | |

To determine the use of the inferential statistical test, the Shapiro-Wilk normality test was performed, for which this test is used for small samples (<30 individuals) in this case the degrees of freedom was 14 and the criterion used for the determination of normality was:

| | | |
|---|---|---|
| P-value (notes before)= 0,192 | > | α = 0,05 |
| P-value (notes after)= 0,184 | > | α = 0,05 |

According to the Shapiro-Wilk normality test, the data come from a normal distribution because the pretest scores were 0.192 which is greater than α = 0.05, likewise, the post test scores were 0.184, which were also greater than α = 0.05, therefore, it is determined that they are normal data, for this the inferential statistic of Student's t for related or paired samples was used to test the hypothesis.

**Table 8.** Descriptive statistics for related samples

| Related sample statistics | | | | | |
|---|---|---|---|---|---|
| | | Media | N | Desviación típ. | Error típ. de la media |
| Par 1 | Pre test | 11,79 | 14 | 1,805 | ,482 |
| | Post test | 17,00 | 14 | 2,320 | ,620 |

The statistical results for related samples are shown in table 8, where the mean was 11.79 in the pre-test and in the post-test is 17.00, showing that the arithmetic mean of the post-test is higher, i.e. after having carried out the treatment with the application of the Model ChemLab and PhET simulator, the development of the learning sessions in the laboratory practices in the Chemistry Laboratory course, the students obtained higher marks.

The results presented relate to [23] where the mean had a value of 6.97 in the fifth semester; 7.07 in the third semester and a mean of 7.06 in the second semester, which shows that there is no significant difference between the means, corroborating with the hypothesis test proposed. In addition, another study by [27] report that by applying alternative methodologies the group that was given the treatment had significant improvement in developing scientific competences compared to the control group, for this it is important to design diverse strategies based on needs, in order to improve learning purposes. In the research found by [24]. The students, in order to be active in the development of the learning session in chemistry courses, must know how to formulate through the methodology of problematisation using simulators such as PhET through the didactic sequence. In the same way [25] in its results states that the use of the Crocodile Chemistry virtual laboratory as a methodological strategy favours the learning of chemistry in students, by actively carrying out experiences to strengthen critical and scientific thinking, linking theoretical learning with practice.

**Table 10.** Inferential statistics for the evaluation of the pre-test and post-test.

| Related samples test | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Related differences | | | | | t | gl | Sig. (bilateral) |
| | | Media | Desviación típ. | Error típ. de la media | 95% Intervalo de confianza para la diferencia | | | | |
| | | | | | Inferior | Superior | | | |
| Par 1 | Pre test - Post test | -5,214 | 1,122 | ,300 | -5,862 | -4,567 | -17,393 | 13 | ,000 |

Table 10 shows that the Student's t-value was 17.393 with a p-value = 0.000; proving the hypothesis that the alternative hypothesis is accepted as demonstrated in the hypothesis test.

## Hypothesis testing

Esta prueba se emplea para determinar la efectividad de un tratamiento o procedimiento en observaciones relacionadas, el procedimiento para la prueba de hipótesis es el siguiente:

1. **Statement of the hypothesis**

$$H_o = \mu_{1=}\mu_2$$

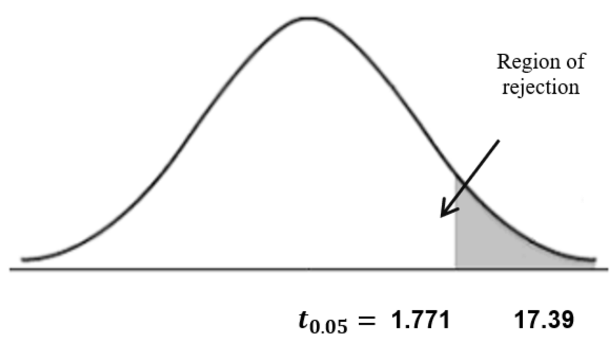
$$H_o = \mu_1 > \mu_2$$

2. **Level of significance**

$$\alpha = 0{,}05$$

3. **Critical Value**

The critical value using Student's t-distribution with 14 degrees of freedom was 1.1771.




4. **Test statistic**

con n-1 gl

$\boldsymbol{t} = 17{,}39$

p-value **=** 0.000

5. **Decision rule**

The null hypothesis is rejected when the value of $\boldsymbol{t_c} > \boldsymbol{t_t}$

The results are similar to those found by [26] where they state that the use of the Model ChemLab virtual laboratory simulator has the potential to enhance the teaching and learning experience in the field of chemistry. This is achieved by enabling a more structured acquisition of knowledge, which in turn facilitates the creation of meaningful learning for students. On the other hand Mena (2021) concludes that the laboratory practices in science courses, when applying virtual laboratories, are aimed at strengthening teamwork competences, where students develop autonomy, leadership and decision making. Likewise, another study concludes that students who used the Model Chemlab virtual simulator as a learning strategy, obtained a higher performance compared to the control group, had a greater growth in the attitudinal and cognitive dimension, demonstrating greater motivation and understanding of the knowledge related to the subject of study [12].

[22] in their research, they identify and justify the key skills that students need to apply problem-based mathematics instruction in a public school, demonstrate that the problem-seeking task system is effective in developing these skills, and has been experimentally proven to improve students' mathematics readiness. Also [27] state that in terms of didactic implications, they are very useful to guide teachers in the development of scientific competences through a structure of knowledge, which implies designing activities that clarify the relationship between the different knowledge and skills that students must acquire, in addition, it is fundamental to base these activities on an initial diagnosis that identifies students' weaknesses and focuses on addressing them, sequencing activities according to the students' cognitive level is crucial to obtain good results, using relevant socio-scientific contexts, especially those related to their immediate environment, can motivate students and show them the importance of learning science.

## CONCLUSIONS

The study concludes that the combined use of the Model Chemlab and PhET simulators as teaching resources has proven to have a positive impact on the learning of chemistry in university students. This translates into the development of scientific competences that allow them to investigate using scientific methods and build knowledge. Thanks to the application of these simulators, students have acquired skills and abilities that have helped them in the learning process. They have been able to formulate enquiry questions, formulate hypotheses and recognise independent and dependent variables in experiments. Consequently, the use of these resources has significantly enriched the learning sessions and boosted their understanding of chemistry in an effective way.

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