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Oculus space lab impact on chemistry learning in PrepaTec students

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Introduction: During the Covid-19 pandemic, more than 27,000 students enrolled in high school at Tecnologico de Monterrey did not perform face-to-face laboratory practices, so it was not possible to objectively demonstrate the development and strengthening of their learning and the acquisition of scientific skills involved in practical work. This research work revolves around evaluating a tool in which the student can perform laboratory practices using immersive virtual reality.

Objective: Therefore, the objective of the experiment was to measure the impact of laboratory practices using immersive virtual reality on learning and academic performance.

Methods: This study used a quantitative approach, with a control group and an experimental group to which a pre-test and post-test were applied. The sampling technique was non-probabilistic by convenience. To analyze the data we applied descriptive and inferential statistics using Shapiro-Wilk to test normality and Wilcoxon signed-rank test for non-parametric data. The sample consisted of 29 students from PrepaTec Campus Cuernavaca, who took science courses during the summer period of 2023, the ages of the participants ranged between 16 and 18 years old.

Results: The results indicate that significant differences were found between the control and experimental groups of the practices. A significant difference was observed in the control group in lab 0, while positive trends were found in the experimental group in lab 1.

Discussion: The results of this study suggest that the implementation of virtual reality to perform laboratory practices has potential, but its effectiveness depends on several factors, including the training of students in the use of augmented realities, the pedagogical design of the intervention, and the adaptation time required.

KEYWORDS

chemical laboratory, virtual reality, chemistry learning, practices, learning, chemistry, educational innovation, higher education

1 Introduction

In December 2019, the COVID-19 disease marked moments of global distress, education at all levels underwent substantial transformations to continue remotely teaching classes and with the activities of educational institutions, adopting technologies that were barely known by some teachers and students (UNESCO, 2020).

While the academic lag suffered during the isolation period has had repercussions on the acquisition of academic skills and competencies, it is highlighted that the greatest impact suffered and today analyzed by UNESCO, UNICEF and other institutions is that in Mexico alone, more than 2.5 million students dropped out of their primary, secondary and higher education studies in 2020, and that by 2021, that number would have doubled (Villarreal Castañeda and Estrada Torres, 2023).

During this period, at the Tecnológico de Monterrey, thanks to the launch of the Flexible and Digital Model, more than 90 thousand students and 10 thousand teachers resumed their classes in an online format, more than 45 thousand synchronous sessions were offered per week and more than 280 thousand class sessions were taught (Tecnológico de Monterrey, 2025). Even so, it is estimated that more than 27,000 students enrolled in the high school level attending distance classes did not have the opportunity to develop face-to-face laboratory practices, among other activities that would allow them to evaluate the development and strengthening of their scientific skills in an objective, clear and precise way (Institute for the Future of Education, 2023).

In some cases, home experiments were proposed to replace certain laboratory practices. In these experiments, the evaluation of the acquisition of scientific skills was subjective and biased to the teacher's criteria. The development of skills and abilities in the laboratory is an essential component of the disciplinary competence "Scientific" described by the Preparatory School of the Tecnológico de Monterrey in its attribute B, where it is specified that students must be able to design, develop and communicate the results of scientific research with a sustainable and ethical perspective, however, the research that occurred in this period did not have the experimental components that promote the development of motor skills or the knowledge to manipulate materials, equipment and instruments in a chemistry laboratory (PrepaTec, 2023).

As a result of this problem, science classes, specifically chemistry, became boring and tedious since only the theoretical and abstract part of what in the syllabus corresponded to laboratory practices was addressed.

Alternatively, some digital resources such as videos were used to show experiments, simulations and representations of practical work, but in all cases, the students stopped experimenting in the real laboratory. It is worth mentioning that finally, it is during the high school period in the subjects of chemistry, biology and physics when scientific competence is marked as mandatory in the curricula of different institutions in Mexico according to the Observatorio de Innovación Educativa (2020) giving students the opportunity to know and manipulate instruments, equipment and laboratory materials, which unfortunately, in this period of pandemic, they were unable to obtain.

Over the years, the pandemic ended, evidencing the multiple efforts to reduce the academic lag where flexible digital models emerged in some of the educational institutions, including the Tecnológico de Monterrey, as previously mentioned. Where multiple virtual tools were used that allowed the evaluation of learning, academic performance and the development of students' skills and competencies when carrying out laboratory practices using different virtual means, but elucidating certain lags in academic issues in different areas of knowledge and also in certain acquired skills (PrepaTec, 2023).

Likewise, it has been important to consider the constant frustration that students experienced when facing the return from isolation to their science classes that include experimental sessions; where a beaker could not be recognized or manipulated, taking measurements or following their experimental laboratory practice manuals became a great challenge for students and teachers of these subjects, a whole problematic transition period that evidenced a great lag in academic competencies and practical skills (Nóvoa, 2023).

One of the most used methods during the pandemic was undoubtedly simulations and videos of chemical processes, however, it is well known that students must be involved in their learning to achieve deeper cognitive levels. According to different learning theories, face-to-face and virtual involvement have different implications (Zambrano and Moya, 2019). Therefore, a team of teachers from PrepaTec designed virtual practices for Oculus VR and they were tested in contrast to traditional practices.

1.1 Use of virtual reality in education

The use of virtual reality (VR) in educational contexts has its roots in mid-20th-century technological developments, such as Morton Heilig's Sensorama in 1962, which integrated stereoscopic vision, sound, vibration, and smells to create a multisensory immersive experience, anticipating the principles of modern VR. This is further supported by the creation of the first head-mounted headset (HMD) by Ivan Sutherland in 1968, considered the direct predecessor of today's headsets (Heilig, 1962; Sutherland, 1968). Beginning in the 2010s, with the popularization of devices such as the Oculus Rift and platforms like Google Expeditions, VR began to establish itself as a tool with pedagogical potential, capable of transforming the way students experience complex concepts (Freina and Ott, 2015).

The potential of VR has been particularly explored in the field of science education. In chemistry education in particular, Van Dinther et al. (2023) highlight that meaningful chemistry education is underpinned by four key features: everyday context, the need-to-know principle, student engagement, and macro-micro connection. Immersive virtual reality (IVR) can be an effective means of developing each of these dimensions. For example, by using virtual environments that simulate everyday chemical phenomena such as fermentation or water contamination, students can connect what they have learned with real-life situations in their environment. This strengthens the first principle, that of everyday context, by placing learning in authentic settings that make the content more relevant and understandable.

The need-to-know principle is activated when students interact with a virtual environment that poses a real-life problem before introducing theoretical concepts. Curiosity and the need to understand what is happening drive an active search for knowledge. In turn, student engagement is enhanced in these immersive environments, as they allow students to make decisions, explore alternatives, and construct knowledge from an active, rather than a receptive, stance. Finally, VR allows simultaneous visualization of the macroscopic level—for example, a color change in a solution—and the microscopic level, such as the movement of ions or the formation of bonds, facilitating the connection between observables and the molecular models that explain the phenomena (Van Dinther et al., 2023).

Several studies have documented the overall benefits of VR for learning. The literature indicates that this technology improves knowledge retention, promotes critical thinking, and strengthens student engagement in the educational process, thanks to its ability to create immersive, multisensory, and interactive experiences (Freina and Ott, 2015; Radianti et al., 2020). In the case of chemistry, these benefits translate into a better understanding of abstract concepts such as molecular structures, bonds, chemical reactions, or energy phenomena, as they can be represented in a visual and manipulable way.

At the high school level, the use of VR in chemistry has shown promising results. For example, in a study conducted in Mexico, the use of immersive technology in organic chemistry classes allowed students to visualize three-dimensional molecules and understand processes such as orbital hybridization or covalent bond formation more intuitively. Participants reported increased motivation and conceptual clarity, especially when addressing abstract topics that often represent a barrier in traditional learning (Santos-Garduño et al., 2021). Furthermore, a broader analysis by Santos-Garduño et al. (2021) shows that 100% of the students surveyed considered that VR had a positive impact on their academic performance, while 80% reported a significantly more immersive learning experience than with conventional methods.

On the other hand, among the main areas of opportunity in the use of virtual reality (VR) for learning chemistry are the persistence of technical barriers, such as the lack of well-designed virtual environments or device malfunctions, which was reported in 13.4% of the articles reviewed in a systematic study (Urzúa Reyes et al., 2021). Likewise, the high cost of implementation represents a significant limitation, especially in institutions with restricted resources, being identified as an obstacle in 10.9% of the cases analyzed (Ndjama and Van Der Westhuizen, 2025). Another recurring challenge is cognitive stress and physical fatigue, such as dizziness or nausea caused by the prolonged use of immersive simulations, present in 8.6% of research in chemistry and STEM areas (Ahmady Falah et al., 2024). Furthermore, some students experience cognitive overload due to the novelty effect, i.e., they focus much of their attention on adapting to the technological interface rather than on conceptual objectives, which limits their use of the immersive environment (Miguel-Alonso et al., 2024). Added to this is the lack of pedagogical integration, as many VR experiences are not aligned with curricular content or have a solid instructional design, which diminishes their educational effectiveness when addressing complex chemistry topics (Checa et al., 2024).

1.2 Developing scientific skills with VR

Recent literature (Gungor et al., 2022) has linked the use of immersive environments with the development of transversal scientific skills, including problem-solving, critical thinking, and collaboration. These skills are enhanced when the experience design includes active components, authentic tasks, and formative feedback. Particularly in chemistry, VR can emulate complex or dangerous experimental environments, allowing students to explore safely and autonomously.

Hernández-de-Menéndez et al. (2019) propose an operational definition of scientific skills using the KIPPAS framework, which groups six fundamental dimensions of learning in laboratory contexts. These skills include knowledge and understanding, defined as the ability to model theoretical concepts, confirm, apply, and solve problems related to disciplinary content; inquiry skills, focused on observing, formulating hypotheses, designing experiments, and understanding the epistemological nature of science; and practical skills, which involve the effective and safe use of scientific instruments and technologies following professional protocols.

They also integrate perception, that is, interest, appreciation, and desire to learn science; analytical skills, such as the ability to infer, interpret, predict, integrate information, and recognize patterns in experimental data; and finally, scientific and social communication, which encompasses collaboration, the presentation of findings, and the preparation of technical reports. These dimensions are aligned with the scientific and engineering practices described by the National Research Council (2012), such as formulating questions, developing models, analyzing data, using mathematical thinking, constructing explanations, and communicating results. According to the authors, these skills can be developed both in physical laboratories and in virtual or remote environments, and their effectiveness depends on multiple factors beyond the type of technology used, such as the perception of presence, interaction, and student motivation (Hernández-de-Menéndez et al., 2019).

The KIPPAS framework is a proposal for assessing learning outcomes in educational laboratory contexts, presented by Hernández-de-Menéndez et al. (2019), whose objective is to offer a structured guide for analyzing and comparing the impact of different types of laboratories (in-person, virtual, and remote) on the development of students' scientific skills.

The KIPPAS acronym is composed of six key categories of learning outcomes:

K—Knowledge and Understanding: conceptual and theoretical development.

I—Inquiry Skills: hypothesis formulation, experimental design, scientific thinking.

P_1—Practical Skills: appropriate use of equipment, instruments, and technical protocols.

P_2–Perception: interest, motivation, and disposition toward learning science.

A—Analytical Skills: analysis, interpretation, and integration of data.

S—Social and Scientific Communication: collaboration, reporting, and communication of findings.

According to the authors, the KIPPAS framework allows for the assessment of educational effectiveness not only based on conceptual content, but also considering the development of practical, cognitive, and communicative skills relevant to scientific and professional contexts.

1.3 Learning theory employed

The instructional design of VR environments in education must consider aspects such as interactivity, immediate feedback, clarity of learning objectives, and curricular integration. In particular, Guruloo and Osman (2023) recommend that virtual laboratories be built based on pedagogical design principles, including constructive alignment and experience-based learning.

Likewise, the evaluation of the impact of these environments should integrate mixed methodologies that allow for the assessment not only of academic performance but also variables such as motivation, perception of usefulness, knowledge transfer, and the development of higher cognitive skills.

The learning theory that underpins the development of the Oculus Space Lab is active learning. This approach emphasizes student engagement through direct interaction with content, experimentation, and problem-solving rather than passive reception of information. In the Oculus Space Lab, learners are immersed in a simulated environment where they manipulate variables, explore virtual phenomena, and make real-time decisions—processes that align with constructivist principles and promote deeper understanding through doing. By encouraging students to take ownership of their learning, the lab fosters critical thinking, reflection, and the transfer of knowledge to new contexts. Research shows that immersive environments based on active learning principles enhance conceptual understanding and increase learner motivation in STEM education (Makransky and Mayer, 2022).

Based on the above, this document shows the evaluation of the academic performance and learning of high school students in a chemistry class when carrying out two practices in the OCULUS Dynamic Space Lab VR virtual laboratory, in contrast to traditional laboratory practices.

Learning is the process that occurs in an individual when he or she assimilates information through experience or practice and consequently presents a change in his or her behavior in a short period of time. On the other hand, Biggs (2005) maintains that learning is a process of social construction that requires knowledge, motivation, activity and interaction (Saénz, 2018).

For his part, Ramírez Gallegos (2017) defines academic performance as the mastery of knowledge that a student has about a subject and can take quantitative or qualitative values. The author considers academic performance as a complex phenomenon in which factors such as school context, gender and educational level influence academic performance.

In the area of science, laboratory experiences are of great importance for the learning process, in this way, Hernández-de-Menéndez et al. (2019) affirm that the heart of learning is in laboratory practices, since students develop competencies and skills for life. The educational laboratory represents a space that allows the validation of theoretical concepts, using various elements and the performance of experiments (Camelo-Quintero, 2019), but they are also spaces of interaction that have been favored by virtualization and in which information technologies are applied (Sanz and Martínez, 2005).

Over the years and with the arrival of the Covid-19 pandemic, educational laboratories were transformed, virtual laboratories became more relevant; the use of these had an impact on the reduction of equipment costs, spaces, maintenance, updates and minimization of risks. According to Reyes et al. (2021) virtual laboratories are sites that simulate learning situations typical of traditional laboratories and virtual laboratory practices constitute a fundamental complement to virtual learning environments.

Virtual reality has been used in various scientific areas, for example, natural sciences, chemistry, biology, computing and even mathematics and has been tested with varying degrees of success. In general, simulations or gamified environments are used that use animated and eye-catching interfaces to present the content. The user's role in these simulations is very interactive, but it is currently observed that the development of technology has surpassed instructional design (Dunnagan et al., 2020).

Virtual reality and augmented reality are becoming frequent scenarios for chemistry subjects. Augmented reality has been described as a suitable tool for instruction or documentation (Naese et al., 2019), while virtual reality is currently used to offer experiential experiences in a laboratory and offer an approach that helps the student overcome fears about traditional laboratories (Alnagrat Alnagrat et al., 2023).

The design of the practices carried out in the laboratory must then be aligned with the study plans of the subject in question, in addition to ensuring the development of scientific competence. Therefore, in this research, the laboratory practices designed using IVR (Immersive Virtual Reality) technology were considered as an independent variable in contrast to traditional practices, while the dependent variable focused on the analysis of chemistry learning and the academic performance obtained when using this technology.

Dunnagan et al. (2020) used a virtual laboratory to teach students how to use an infrared spectrophotometer and identify the structure of the spectrum. The authors found no significant differences between the academic performance of students who performed the practice in the virtual laboratory and those who performed the practice in the traditional laboratory, thus concluding that this tool represents a great alternative for classes in remote or hybrid learning environments.

Lerma-García et al. (2020) used virtual reality as a teaching technique for chemistry subject and reported a high acceptance of the tool by students and a significant improvement in academic performance, but they emphasize the importance of considering and rethinking the pedagogical foundations and academic intentions of each activity that involves the use of technology.

Brovelli-Sepúlveda et al. (2018) used virtual laboratories in four science courses at the high school level and found a significant improvement in the scientific skills and academic performance of the students. These authors point out a high level of development of critical thinking and decision making in students who used virtual reality compared to those who worked in a traditional laboratory.

The results obtained in the research and articles mentioned above allowed the following hypothesis to be raised for this research. This study consisted of knowing if students who carry out laboratory practices with Immersive Virtual Reality (VR), show a significant improvement in chemistry learning and academic performance, compared to traditional methods.

2 Methods

To evaluate the impact of laboratory practices with immersive virtual reality (IVR) on academic performance and chemistry learning, a study with a quantitative approach and quasi-experimental design was used that allowed comparing the results between an experimental group and a control group. The methodological approach focused on evaluating the academic performance of students when carrying out the practice and their learning through the application of the pretest and posttest.

2.1 Participants and data collection

The study involved 29 bicultural high school students from Tecnológico de Monterrey Campus Cuernavaca high school, who took science subjects during the summer of 2023. The students were divided into two groups, an experimental group with 14 students who carried out two laboratory practices using immersive virtual reality in the Oculus Space Lab laboratory through Oculus ProQuest 2 glasses and a control group with 15 students who carried out the same two practices using the traditional method in the Campus chemistry laboratory, which consisted of carrying out the experiment at a work table with their teammates, using their manual skills and abilities to make measurements, weigh substances, measure quantities of liquids, identify the areas of the laboratory, assemble equipment and manually fill out the practice report. Both groups followed the same instructions when carrying out both practices, the difference was the technological tool used.

2.2 Consent Procedures

The studies involving human participants were reviewed and approved by Novus, Tecnológico de Monterrey (ID N21-252). The patients/participants provided their written informed consent to participate in this study.

2.3 Design of the VR-learning environment

Oculus Space Lab is a replica of the in-person lab; the interface design is based on the physical lab infrastructure on the Campus. The ADDIE instructional model was used as a methodological framework to design the immersive virtual laboratory for chemistry learning (Branch, 2009). In the analysis phase, the learning needs, student profiles, and the scientific skills to be developed, such as observation, hypothesis formulation, and interpretation of results, were identified. Subsequently, in the design phase, the learning objectives, the content to be integrated into the virtual environment, the didactic sequence of the practice sessions, and the assessment instruments aligned with scientific competencies were established. In the development phase, the laboratory scenarios were designed and programmed using 3D modeling and simulation tools, incorporating interactive elements and immediate feedback. The implementation was carried out by integrating the laboratory into the chemistry course, providing students with guided access through immersive devices. Finally, in the evaluation phase, the scientific skills rubric and learning tests (pre- and post-test) were used to assess the laboratory's pedagogical effectiveness. This approach allowed for rigorous instructional design, focused on active and meaningful learning within a technologically advanced environment.

It is important to mention that the Oculus Space Lab laboratory practices follow the scientific method, this methodology governs the face-to-face laboratory practices on Campus.

The workflow for the lab design was as follows:

1. Selection and design of chemistry labs by the team of expert teachers involved in the project.
2. Preparation of the Game Design Document by the project's technology team, considering the teachers' previous work and taking into consideration the limitations of the technology.
3. Submission of the Game Design Document to an expert, external team of programmers, who developed a schedule of activities with dates and responsibilities.
4. Weekly meetings with the entire team (teachers, technology team, and programmers) to review progress.
5. Prototype testing and launch.

The learning environment for the virtual laboratory practices was structured as follows:

Stage 1 PRELAB: The student puts on the virtual reality glasses and observes the board with buttons numbered from 0 to 7, each number represents the number of the practice, presses button 0 and enters the practice Identification of laboratory material, to continue, the safety equipment is put on, this consists of a lab coat, glasses, gloves and industrial shoes, then observes and reads the objective of the practice, he is asked to select a research question, the dependent, independent and control variables and a hypothesis.

Stage 2 EXPERIMENT: The student enters the laboratory and finds a table with materials that must be placed in the reagents, glassware and chemical waste area, then the student is told to identify the areas where the first aid kit, the emergency exit and the fire extinguisher are located, each time the student places a material correctly, he accumulates points that later become a grade.

Stage 3 ANALYSIS: The student is presented with a hypothetical situation related to the practice, example 1: What would happen if hydrochloric acid fell on your clothes? The student must select one of the 3 response options. He/she then answers 4 questions that assess his/her knowledge of the practice and asks if the hypothesis was fulfilled. Based on the answers that the student selected in the questions of stages 1 and 3, a paragraph is shown that shows the analysis of results.

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Stage 4. CONCLUSION: The student is asked to select a conclusion from the 3 shown.

The same procedure is used for practice 1 Recognition and assembly of laboratory material, both practices have a maximum duration of 40 min.

2.4 Evaluation instruments for the experience

To measure student learning, a knowledge test was applied before and after each practice. The tests consisted of 7 questions, each with four response options. The tests were validated by the Academy of Science Teachers of Prepas Tec in Campus Cuernavaca and Campus Estado de México (see Figures 1, 2).

To measure academic performance in the experimental and control groups, the grade obtained by the student when carrying out the laboratory practices was used. The practice carried out in the Oculus Space Lab virtual laboratory and the one carried out in the Campus science laboratory were evaluated under the same criteria. Figure 3 shows the checklist containing the evaluation criteria and which corresponds to an adaptation of the rubric used by Hernández-de-Menéndez et al. (2019).

2.5 Procedure

The study was conducted in three sessions for practice 0 and three sessions for practice 1, each session lasting 50 min. During the first session, the students of the experimental group and the control group answered the pretest, during the second session both groups carried out the laboratory practice, the experimental group used the laboratory with RV Oculus Space Lab and the control group carried out the practice in the science laboratory of the Campus, in the third session both groups answered the corresponding posttest.

2.6 Data analysis

A comparative analysis was made between the results of the pretest, postest and the grades obtained in both practices of the experimental and control groups. The methodological approach employed provided insight into the impact of using technology with RV in education.

The data were analyzed using descriptive and inferential statistics. For descriptive statistics, measures of central tendency, kurtosis, range and skewness were used. For inferential statistics, first, we proved normality distribution, using Shapiro-Wilk test, p-value results < 0.05 determine the use of non-parametric tests. Because we couldn't prove the normality of data, we proceeded to use Wilcoxon Signed-Rank test to compare paired variables of pre-test and post-test.

3 Results

This study involved 29 students divided into two groups, the control group that performed the laboratory practices using the traditional method and the experimental group that performed practices with the RV Oculus Space Lab, in both groups the learning and academic performance variables were evaluated.

To evaluate the learning variable, the results of descriptive and inferential statistics of the pretest and posttest in practices 0 and 1 of the experimental group and the control group were compared.

To evaluate the academic performance variable, the results from descriptive and inferential statistics were compared in the grades obtained by the students in practices 0 and 1 of both the experimental group and the control group.

In both cases, the objective was to determine a statistically significant difference between the mean score of the control and experimental groups. The t-tests are the most widely used statistical analysis method to analyze the difference in means, they are easy to interpret and resistant to deviations from normality.

3.1 Comparison of results of the control group vs. the experimental group Practice 0

The results of applying descriptive statistics to the control group of Practice 0 are shown in Figure 4.

For the control group, we can observe that in the pretest 0, the students obtained an unsatisfactory average score of 55.1 ± 16 and the highest score was 72. In the posttest 0, the group obtained an average score of 68.9 ± 20.9 and the highest score was 100. When carrying out practice 0 in the traditional way, the students obtained an average score of 73.1 ± 16.7 and the highest score was 100. The results of applying descriptive statistics to the experimental group of practice 0 are shown in Figure 5.

For the experimental group, we can observe that in the pretest 0, the students obtained an unsatisfactory average score of 67.9 ± 21.1 and the highest score was 100. In the posttest 0, the group obtained an average passing score of 71.7 ± 11.2 and the highest score was 86. When carrying out practice 0 in the Oculus Space Lab virtual laboratory, the students obtained an average score of $65.3.1 \pm 20$ and the highest score was 96.

The results of applying inferential statistics to the control and experimental groups of practice 0 are shown in Figure 6.

In the control group of Practice 0, an increase in the mean of 13.73 points was observed over the posttest score. The analysis showed a Pearson correlation of 0.782 between the pretest and posttest scores. The T-test indicated that there was a significant difference between the pre- and post-test means ($t = -4.075$, $p < 0.001$, 95% CI). These results suggest that the participants in the control group showed a significant improvement in their learning after completing Practice 0 in the traditional way.

The experimental group of Practice 0 showed an increase in the mean of only 3.85 points over the posttest score. The Pearson correlation between the measurements was lower ($r = 0.095$). The T-test showed no significant differences between the two measurements ($t = -0.628$, $p = 0.270$ for a one-tailed test, $p > 0.05$). Although the mean increased slightly, the results suggest that participants in the experimental group did not show significant improvement in their learning after performing practice 0 in the Oculus Space Lab virtual laboratory.

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Pretest Practice 0

1. _____Laboratory material used to separate two miscible liquids:
   a. Burette
   b. Graduated test tube
   c. Separation funnel
   d. Ball-shaped flask

2. ____Laboratory material used to heat liquids whose vapors should not be in contact with the heat source:
   a. Erlenmeyer flask.
   b. Universal support
   c. Bunsen burner and alcohol lamp
   d. Flat-bottomed ball-shaped flask

3. ______Material that allows the transformation of gases that are released in the distillation process:
   a. Graduated test tube
   b. Bunsen burner and alcohol lamp
   c. Condenser or coolant.
   d. Distillation tail

4. ______Which of the following options is considered a medium flame source?
   a. Tripod
   b. Asbestos blanket or cloth
   c. Alcohol lamp and Bunsen burner
   d. Porcelain capsule

5.______ A volatile compound, a corrosive compound, and an oxidizing compound are placed on the same shelf.
   a. Yes, they go on the same shelf.
   b. No, only the corrosive and oxidizing compound
   c. No, only the volatile and oxidizing compound
   d. No, each one goes on its corresponding shelf

6. ______ Select the areas of a chemistry laboratory
   a. First aid kit and emergency exit
   b. First aid kit, fire extinguisher, and emergency exit
   c. Emergency exit and first aid kit
   d. Emergency exit only.

7.- ______ To classify a reagent and take it to its corresponding area, what aspect should you observe?
   a. Label
   b. Bottle color
   c. Smell
   d. None of the above.

FIGURE 1
Pretest practice 0.

3.2 Comparison of results of the control group vs. the experimental group Practice 1

The results of applying descriptive statistics to the control group of Practice 1 are shown in Figure 7.

For the control group of practice 1 we can observe that, in the pretest, the students obtained a satisfactory average score of 88.46 $\pm$ 16 and the highest score was 100. In posttest 0, the group obtained an average score of 88.39 $\pm$ 16.6 and the highest score was 100. When carrying out practice 1 in the traditional way, the students obtained an average score of 67 $\pm$ 14.5 and the highest score was 84.5.

The results of applying descriptive statistics to the experimental group of practice 1 are shown in Figure 8.

For the experimental group of Practice 1, we can observe that in the pretest, the students obtained an average score of 74.5 $\pm$ 24.2 and the highest score was 100. In the post-test, the group obtained an average score of 82.2 $\pm$ 20.6 and the highest score was 100. When carrying out Practice 1 in the traditional way, the students obtained an average score of 52 $\pm$ 12.7 and the highest score was 80.

The results of applying inferential statistics to the control and experimental groups of Practice 1 are shown in Figure 9.

In the control group Practice 1, an increase in the posttest means of 0.75 points was observed. The analysis showed a Pearson correlation of 0.613 between the pretest and posttest scores. The paired T-test did not indicate a significant difference between the pre- and posttest means ($t = -0.1947$, $p = 0.8486$, bilateral). These results suggest that the participants of the control group did not show significant changes in their learning after carrying out Practice 1 in the traditional way.

The experimental group of Practice 1 showed an increase in the posttest mean of 7.71 points. The Pearson correlation between the measurements was 0.609. Despite the increase in the mean, the paired T-test did not show significant differences between the two measurements ($t = -1.439$, $p = 0.173$ for a two-tailed test). These results suggest a trend toward improvement in the learning of the students of the experimental group.

At the traditional significance level ($\alpha = 0.05$), neither of the two groups in Practice 1 showed a significant change from pretest to posttest. The experimental group showed a greater variation

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Pretest Practice 1

1. _____Laboratory area where you see the water tap, gas tap, scale, heating grill and some glass materials, this is where you carry out your experiments.
   a. Equipment area
   b. Extraction hood
   c. Reagent area
   d. Worktable

2. _____Laboratory area where it is mandatory to use safety glasses and nitrile gloves, it is a ventilation area used to capture flammable, irritating and/or corrosive vapors.
   a. Equipment area
   b. Extraction hood
   c. Worktable
   d. Reagent area

3. _____Laboratory area where the spectrophotometer, rotary evaporator, centrifuge, drying oven, incubator, pH meter and HPLC are located.
   a. Equipment area
   b. Extraction hood
   c. Worktable
   d. Reagent area

4. ____What equipment or services does the laboratory have to handle emergencies?
   a. Reagent area and worktable
   b. Washing area and equipment area
   c. Sink and emergency exit
   d. Shower, eyewash and first aid kit

5. _____Which of the following images corresponds to the fractional distillation assembly?

6. ____Which of the following images corresponds to the assembly of the titration process?

7. ____Which of the following images corresponds to the decantation assembly?

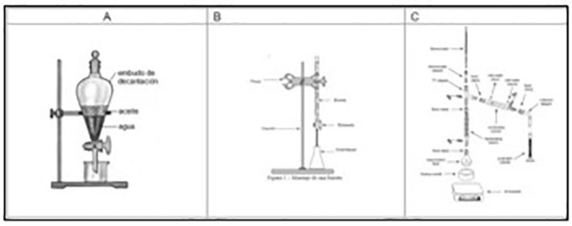

FIGURE 2
Pretest practice 1.

in the mean, but it was not statistically significant ($p = 0.173$ in two tails and $p = 0.087$ in one tail). Although the results show an improvement in the scores of the experimental group, there is not enough evidence to reject the null hypothesis that there is no difference in learning in either of the two groups.

4 Discussion

The results of the statistical analysis allow us to evaluate the effectiveness of the practices implemented in the control and experimental groups and to pay special attention to the impact of the practices with RV on the academic performance and learning of chemistry. When comparing the pretest and posttest results of both groups, for practices 0 and 1, notable differences in the students' learning are evident and when comparing the students' grades in both practices, differences in the academic performance of the students in both groups are evident.

The data obtained in practice 0 show a significant increase in the learning and academic performance of the students in the control group, while for the students in the experimental group, the practice with RV did not generate a significant improvement in learning and academic performance. The observed trend suggests that practice 0, when dealing with the identification of laboratory material and areas, becomes more significant for the student than the traditional way because it generates an experiential experience strengthened by physical contact with the instruments and equipment, together with the sensations that the student experiences in the classroom environment (smells, colors, textures and sounds).

The results of the experimental group for practice 0 also suggest a lack of training of the students to perform practices with RV, given that it was the first practice with the use of technology.

Regarding practice 1, the difference in means between the pretest and posttest of the control group was minimal and without statistical significance, which suggests that the students already had a high level of knowledge on the topic of the practice

Skill	Description	Evaluated section of the report	How is it assessed?	Rating percentage
Inquiry Skill	...make observations, create and test hypotheses, generate experimental designs and/or acquire an epistemology of science	Research question and hypothesis	The student correctly writes or selects a hypothesis and a research question	0.2
Analytical skills	...critique, predict, infer, interpret, integrate, and recognize patterns in experimental data and use these to generate models of understanding	Results of experiments	The student correctly performs the experiments in the practice	0.2
Practical skill	...can efectively use scientifc equipment, technology, and instrumentation, follow technical and professional protocols, and/ or demonstrate profciency in physical lab techniques, procedures, and measurements	Results of team building	The student correctly assembles the equipment used in the practice	0.2
Communication skills	are able to collaborate, summarize and present experimental fndings, prepare scientifc reports and graph and display data	Discussion	The student correctly writes or selects the findings of his experiment	0.2
Perception	engage in and express interest, appreciation and/or desire for science and science learning	Conclusion	The student correctly selects or writes a conclusion	0.2

FIGURE 3
Checklist for measuring practice grade.

Recognition and assembly of laboratory equipment, since, in their previous science course, the students had already performed equipment assembly. In the experimental group, a greater increase in the mean was observed without reaching a level of statistical significance; the trend observed suggests that applying RV practices could favor students with previous experience in the subject of the practice.

The lack of statistical significance in some cases may be due to variability in student performance or the learning curve associated with the use of innovative technologies. Previous research has pointed out that the introduction of digital environments in education can generate an initial adaptation phase, a factor that could have affected the effectiveness of RV in this study (Huwer et al., 2019). Similarly, the Pearson correlation in the experimental group in practice 0 was low ($r = 0.095$), suggesting that external factors such as familiarity with technology or students' self-efficacy in digital environments could have influenced the results.

On the other hand, it is important to consider the students' perception of the usefulness and usability of the VR, previous research has shown that the acceptance of new technologies in education depends largely on the perceived ease of use and alignment with students' learning styles (Fiorella and Mayer, 2021). The low Pearson correlation observed in practice 0 could indicate that although the tool is innovative, its integration into the learning dynamics was not completely smooth. In this sense, it is recommended that qualitative measurements be included in future studies to better understand the students' experience and their perception of the usefulness of RV in chemistry learning.

Contro group. Practice 0					
Pre-lab 0		*Post-lab 0*		*Práctica 0*	
Mean	55.13333333	Mean	68.86667	Mean	73.1
Standard Error	4.141389997	Standard Error	5.415029	Standard Error	4.315691
Median	58	Median	72	Median	78.37
Mode	58	Mode	72	Mode	78.67
Standard Deviation	16.03953449	Standard Deviation	20.97232	Standard Deviation	16.7146
Sample Variance	257.2666667	Sample Variance	439.8381	Sample Variance	279.3779
Kurtosis	1.376324532	Kurtosis	0.092434	Kurtosis	0.271046
Skewness	-1.182899023	Skewness	-0.8477	Skewness	-0.70806
Range	56	Range	71	Range	62.24
Minimum	16	Minimum	29	Minimum	37.76
Maximum	72	Maximum	100	Maximum	100
Sum	827	Sum	1033	Sum	1096.5
Count	15	Count	15	Count	15

FIGURE 4
Descriptive statistics for the control group of practice 0.

Experimental group. Practice 0					
Prelab 0		*Post-lab 0*		*Práctica 0*	
Mean	67.85714286	Mean	71.71429	Mean	65.28571
Standard Error	5.650884539	Standard Error	2.989779	Standard Error	5.349775
Median	72	Median	72	Median	69
Mode	72	Mode	72	Mode	39
Standard Deviation	21.14367388	Standard Deviation	11.18673	Standard Deviation	20.01703
Sample Variance	447.0549451	Sample Variance	125.1429	Sample Variance	400.6813
Kurtosis	0.354033642	Kurtosis	-1.25359	Kurtosis	-0.19919
Skewness	-0.452205242	Skewness	0.008383	Skewness	-0.50946
Range	72	Range	29	Range	70
Minimum	28	Minimum	57	Minimum	26
Maximum	100	Maximum	86	Maximum	96
Sum	950	Sum	1004	Sum	914
Count	14	Count	14	Count	14

FIGURE 5
Descriptive statistics for the experimental group of practice 0.

t-Test: Paired Two Sample for Means						
Control group Practice 0				**Experimental group Práctica 0**		
	Pretest C0	*Postest C0*			*Pretest E0*	*Postest E0*
Mean	55.13333	68.86667		Mean	67.85714	71.71429
Variance	257.2667	439.8381		Variance	447.0549	125.1429
Observations	15	15		Observations	14	14
Pearson Correlation	0.782958			Pearson Correlation	0.095428	
Hypothesized Mean Difference	0			Hypothesized Mean Difference	0	
df	14			df	13	
t Stat	-4.075186			t Stat	-0.62864	
P(T<=t) one-tail	0.000568			P(T<=t) one-tail	0.270237	
t Critical one-tail	1.76131			t Critical one-tail	1.770933	
P(T<=t) two-tail	0.001136			P(T<=t) two-tail	0.540474	
t Critical two-tail	2.144787			t Critical two-tail	2.160369	

FIGURE 6
Inferential statistics for the experimental and control groups of practice 0.

Control group Practice 1							
Pretest C1			***Postest C1***			***Practice C1***	
Mean	88.46666667		Mean	88.3929		Mean	67.0833
Standard Error	4.106750154		Standard Error	4.43673		Standard Error	3.75227
Median	100		Median	87.5		Median	70
Mode	100		Mode	87.5		Mode	77
Standard Deviation	15.90537495		Standard Deviation	16.6007		Standard Deviation	14.5325
Sample Variance	252.9809524		Sample Variance	275.584		Sample Variance	211.193
Kurtosis	0.735754252		Kurtosis	7.19634		Kurtosis	4.46665
Skewness	-1.304114824		Skewness	-2.44894		Skewness	-1.81364
Range	48		Range	62.5		Range	59.5
Minimum	52		Minimum	37.5		Minimum	25
Maximum	100		Maximum	100		Maximum	84.5
Sum	1327		Sum	1237.5		Sum	1006.25
Count	15		Count	14		Count	15

FIGURE 7
Descriptive statistics for the control group of practice 1.

The findings of this study suggest that the implementation of RV to perform laboratory practicals has potential, but its effectiveness depends on multiple factors, including the training of students in the use of extended realities, the pedagogical design of the intervention, and the adaptation time needed. Future research could focus on exploring strategies to improve the integration of virtual reality in the classroom, ensuring that students develop prior digital skills that allow them to take full advantage of this technology. It would also be pertinent to analyze the long-term impact of these tools on knowledge retention and student motivation in learning chemistry.

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Experimental group Practice 1

	Pretest E1	Postest E1	Practice E1
Mean	74.5	82.2143	52.6429
Standard Error	6.465886815	5.50841	3.40589
Median	85.75	88	50
Mode	100	100	52
Standard Deviation	24.19313316	20.6106	12.7437
Sample Variance	585.3076923	424.797	162.401
Kurtosis	-0.323960145	-0.3429	0.23731
Skewness	-0.848422105	-0.75845	0.82041
Range	76	62.5	46
Minimum	24	37.5	34
Maximum	100	100	80
Sum	1043	1151	737
Count	14	14	14

FIGURE 8
Descriptive statistics for the experimental group of practice 1.

t-Test: Paired Two Sample for Means

	Control group practice 1			Experimental group practice 1	
	Pretest C1	Postest C1		Pretest E1	Postest E1
Mean	87.64286	88.392857	Mean	74.5	82.214286
Variance	261.478	275.58379	Variance	585.3077	424.7967
Observations	14	14	Observations	14	14
Pearson Correlation	0.613797		Pearson Correlation	0.609433	
Hypothesized Mean Difference	0		Hypothesized Mean Difference	0	
df	13		df	13	
t Stat	-0.194799		t Stat	-1.439016	
P(T<=t) one-tail	0.424281		P(T<=t) one-tail	0.086893	
t Critical one-tail	1.770933		t Critical one-tail	1.770933	
P(T<=t) two-tail	0.848562		P(T<=t) two-tail	0.173786	
t Critical two-tail	2.160369		t Critical two-tail	2.160369	

FIGURE 9
Inferential statistics for the experimental and control groups of practice 1.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval was evaluated by the internal committee of Novus in agreement with the institutional committee. Written informed consent from the participants was applied in this study in accordance with the national legislation and the institutional requirements.

Author contributions

ER: Writing – original draft, Writing – review & editing, Conceptualization, Investigation, Validation, Methodology, Data curation, Formal analysis, Visualization. LV: Conceptualization, Investigation, Validation, Writing – original draft. OS: Methodology, Project administration, Resources, Writing – original draft. LR: Methodology, Validation, Conceptualization, Writing – original draft. LA: Data curation, Software, Conceptualization, Writing – original draft. CL: Writing – review & editing, Data curation, Formal analysis, Methodology, Resources.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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