Educación Química

Didáctica de la Química

Virtual teaching-learning of the experimental component of chemistry: a didactic strategy

Enseñanza-aprendizaje virtual del componente experimental de la Química: una estrategia didáctica

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Resumen

La pandemia inducida por el COVID-19 provocó que el proceso de enseñanza-aprendizaje en las universidades se realice a través de la modalidad virtual. El aprendizaje experimental de las ciencias químicas bajo esta modalidad constituye un reto para los estudiantes, pues las prácticas de laboratorio están diseñadas para desarrollarse de manera presencial. El objetivo de esta investigación fue elaborar una estrategia didáctica para la enseñanza del componente experimental de la química en la modalidad virtual. Para ello se utilizaron software de simulación (***VirtualLab ChemCollective***), software de grabación (***Zoom Meetings*** y ***Google Meet***), software de edición de video (Camtasia, ***Ice Cream Video Editor***) y la plataforma ***Moodle***. Se implementaron las cuatro fases de la estrategia didáctica elaborada, que incluyó toda la documentación necesaria para ello (cronograma, guías de estudio, material didáctico, entre otros) y se aplicó una encuesta a 980 estudiantes que participaron en el estudio. Una vez evaluada la estrategia didáctica, la asistencia a clase fue del 88,6 por ciento, la nota media obtenida por los estudiantes fue de 7,8 puntos sobre 10 posibles; el 78,0 por ciento del total, y más del 94 % de los educandos encuestados se mostraron satisfechos con la calidad del proceso de enseñanza-aprendizaje del componente experimental realizado virtualmente. Se concluyó que la asistencia tuvo un comportamiento similar en el semestre evaluado en comparación con el periodo anterior, por lo que la modalidad virtual utilizada en el semestre analizado no influyó en la retención de los estudiantes, y que la calificación promedio se incrementó en 4,4 %; lo que corrobora la efectividad de la estrategia didáctica aplicada.

Palabras clave: química, estrategia didáctica, aprendizaje experimental, enseñanza-aprendizaje, modalidad virtual.

Abstract

The pandemic induced by COVID-19 caused the teaching-learning process in universities to be carried out through the virtual modality. Experimental learning of chemical sciences under this modality constitutes a challenge for students, because laboratory practices are designed to be developed in a face-to-face manner. The objective of this research was to develop a didactic strategy for teaching the experimental component of chemistry in the virtual modality. For this purpose, simulation software (VirtualLab ChemCollective), recording software (Zoom Meetings and Google Meet), video editing software (Camtasia, Ice Cream Video Editor) and the Moodle platform were used. The four phases of the didactic strategy developed were implemented, which included all the necessary documentation (schedule, study guides, didactic material, among others) and a survey was applied to 980 students who participated in the study. Once the didactic strategy was evaluated, class attendance was 88.6 percent, the average grade obtained by the students was 7.8 points out of a possible 10; 78.0 percent of the total, and more than 94 % of the students surveyed were satisfied with the quality of the teaching-learning process of the experimental component carried out virtually. It was concluded that attendance had a similar behavior in the evaluated semester compared to the previous period, so that the virtual modality used in the analyzed semester did not influence student retention, and that the average grade increased by 4.4 %; which corroborates the effectiveness of the didactic strategy applied.

Keywords: chemistry, didactic strategy, experimental learning, teaching-learning, virtual modality.

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Introduction

Information and communication technologies (ICTs) are increasingly present in society. Economic, social and cultural processes, among others, are influenced by their application. General education, and higher education in particular, is one of the sectors that has been most impacted by ICTs to develop the teaching-learning processes of each of the subjects taught in universities, in their different careers.

With the advent of the 21st century came the era of the "digital natives", who are those who study at universities today. Current university students arrived at the university with a knowledge, and in many cases, a mastery of ICTs, which facilitates the use of these technologies in their learning, as long as teachers implement didactic strategies in their teaching-learning processes that contemplate the use of them. On the other hand, many university professors are currently considered "digital immigrants", as they have insufficient digital skills and competencies. Minimizing this cognitive gap is a challenge in contemporary university education.

Literature Review

Since the beginning of the 21st century, ICTs have been revolutionizing how to teach and how to learn (Rosas, De Ita & González, 2009). There are currently three educational scenarios: the virtual one, mediated by virtual learning platforms such as Moodle, the traditional one, where students interact face-to-face with their teacher, and the hybrid one, where virtual and traditional education coexist.

The task of teaching chemical experiments in a traditional laboratory has some limitations. For example, many phenomena in chemical experiments are unexplainable or unobservable, some chemical experiments are dangerous, and some chemicals are expensive. (Mutlu & Sesen, 2020)

ICTs are useful to develop learning in the classroom, motivate students and support the pedagogical and didactic strategies implemented (Yukhymenko et al., 2021). "The experimental curriculum has been viewed as having great importance in helping students grasp difficult concepts through hands-on practice." (Tsai, Ho & Nisar, 2021, p. 1)

This has forced teachers to implement didactic strategies and methodologies incorporating in them, necessarily, the application of ICTs in the different phases of their classes (Vergara, 2019), and in each of the components of the teaching-learning process. "The introduction of virtual simulation technology from experimental teaching ... is of unique significance for the curriculum design of chemistry subjects in colleges and universities. / … promotes the in-depth integration of theoretical knowledge and experiment in chemistry teaching…" (Li, Cao & Luo, 2021, p. 2-3)

Nowadays, the potential of ICTs to favor teaching and learning processes in universities is undeniable, as long as they are incorporated into these processes in an adequate didactic way that motivates students and truly allows them to learn. However, ICTs by themselves do not guarantee learning; therefore, it is necessary that teachers apply didactic strategies that allow the active participation of students, which favor the development of skills to learn how to learn.

These technologies are being applied not only in traditional teaching-learning processes, but are already being applied, quite widely, in the delivery of virtual laboratories, using virtual reality technique (Vergara, 2019), virtual simulation (Hou et al., 2023; Wang et al., 2021; Li, Cao & Luo, 2021), virtual experiments (Tsai, Ho & Nisar, 2021) and virtual experimentation environments (Verstege, Vincken & Diederen, 2021). A study by Vergara (2019) shows that the number of scientific articles published in SCOPUS on virtual reality in the period 2000-2018 grew from 2,000 articles in 2000 to more than 10,000 in 2018.

Rojano, López and López (2016), referring to Hennessy et al. (2007), argue that "It is increasingly common to include in laboratory practices simulations, visualizations, innovative teaching resources and even support with the presence of virtual laboratories in practice sessions." (p. 228) Likewise, Chan et al. (2021), in their review on virtual chemistry laboratories, said, "The results of this review conclude that virtual chemistry laboratories are viable as an effective complementary tool or as an alternative to hands-on laboratories..." (p. 12)

Recent research corroborates Rojano, López and López (2016) and confirms the effectiveness and efficiency of virtual laboratories compared to face-to-face laboratories. Thus, Hou et al. (2023) designed a virtual simulation experiment for teaching experimental learning, Wang et al. (2021) created a virtual simulation experimental teaching network platform for experimental teaching and management, Li, Cao and Luo (2021) applied virtual simulation technology in university chemistry teaching practice and evaluated its impact, and Tsai, Ho and Nisar (2021) proposed a virtual chemistry laboratory, which they designed by combining an application of virtual experiments with physical teaching materials.

The advantages of virtual laboratories in teaching-learning processes have been pointed out by many authors in the last decade. The main advantages associated with the experimental component of Chemistry are:

- Costs are reduced, since there is no consumption of reagents, no use of equipment, materials and utensils, and no maintenance costs are required (García & Entrialgo, 2015; Román et al., 2018, Tsai, Ho & Nisar, 2021).
- Avoid accidents due to the handling of equipment, materials, utensils and, above all, chemical reagents (Vergara, 2019, Tsai, Ho & Nisar, 2021).
- They can simulate dangerous, time-consuming and expensive experiments (Verstege, Vincken & Diederen, 2021).
- No waste is generated, as no real materials and reagents are used in the experiments (Tsai, Ho & Nisar, 2021)
- They allow teachers to serve large groups of students at once (Vergara, Rubio & Lorenzo, 2017).
- They offer different possibilities that favor the teaching-learning process (Vergara, Rubio & Lorenzo, 2018), such as: interactivity options, transparency of areas, enlargement of areas to see interesting details, changing the speed of execution of a trial to check execution details, etc.

- They can promote learning from mistakes, without causing a significant increase in time, effort or costs (Verstege, Vincken & Diederen, 2021).
- They promote student autonomy and personalization of educational practice by facilitating the design desired by the teacher (Catalán, 2014).
- They allow repeating the test or experiment as many times as the student wishes (Vergara, 2014).
- They allow the performance of practical exercises interactively to systematize the experimental learning outcomes (Monge & Méndez, 2007; Vergara & Rubio, 2015; Vergara et al., 2016).
- They are free from the restrictions imposed by time, space and limited equipment that come with face-to-face teaching, but they undoubtedly maintain communication between students and teachers (Verstege, Vincken & Diederen, 2021; Li, Cao & Luo, 2021; Marqués, 2013).
- They allow students to focus on the process rather than the equipment, promote active participation with little or no loss of time, and allow experiments to be repeated in a safe environment (Tatli & Ayas, 2010).

Abraham (2011) presented in a review of three decades of research on laboratory learning the following conclusions:

> 1) while general chemistry instructors identify concepts as the most important outcome of laboratory learning, the instructional strategies used do not align with what is known about how to teach these concepts effectively, 2) students are able to identify important differences between verification-type laboratory experiments and more inquiry-based approaches, including whether there is an emphasis on laboratory skills and scientific processes, and 3) inquiry-based approaches in the laboratory are more effective at promoting students' conceptual understanding and positive attitudes toward science. (p. 150)

Recently, Chan et al. (2021) posited that "Interactivity and autonomous learning are aspects of virtual chemistry laboratories that make these learning environments constructivist and learner-centered." (p. 11) In consequence, "... it is necessary to develop necessary and applicable innovative simulation experiment teaching resources according to the course conditions." (Li, Cao & Luo, 2021, p. 4)

Problem situation

At the Technical University of Manabí, by virtue of the epidemiological situation existing since march 2020, which caused the declaration of the pandemic induced by COVID-19, the ordinary academic period (OAP) june-october 2020 (OAP S1 2020) was carried out through the asynchronous virtual modality and, therefore, also the experimental component (Laboratory) of the subjects in charge of the Department of Chemistry, belonging to the Faculty of Basic Sciences. This implied the development of laboratory practices virtually.

Until then, the development of the experimental component of the chemical sciences subjects was face-to-face. For the first time, laboratory practices would be carried out through the virtual modality, which would be a challenge that teachers and students would have to face.

In a diagnosis carried out on the knowledge that teaching technicians and subject teachers had about ICTs, it was found that they could be classified as informed skeptics (Yukhymenko et al., 2021), which are those people who are characterized by having a somewhat adequate general knowledge of technology; however, they have a low perceived usefulness of it, and little attitude towards teaching and learning with technology; i.e., they tend not to use technology for teaching and learning.

In view of the above, the objective of the research is to implement a didactic strategy for teaching the experimental component of the subjects pertaining to chemical sciences in the virtual modality at the Technical University of Manabí in the OAP S1 2020.

Methodology

Mixed research was used: quantitative in the theoretical design and proposed solution to the problem, with the measurement of quantitative variables such as academic performance, and qualitative in the application of some techniques, such as the survey and discussion workshops, for the collection of non-numerical information (Figure 1).

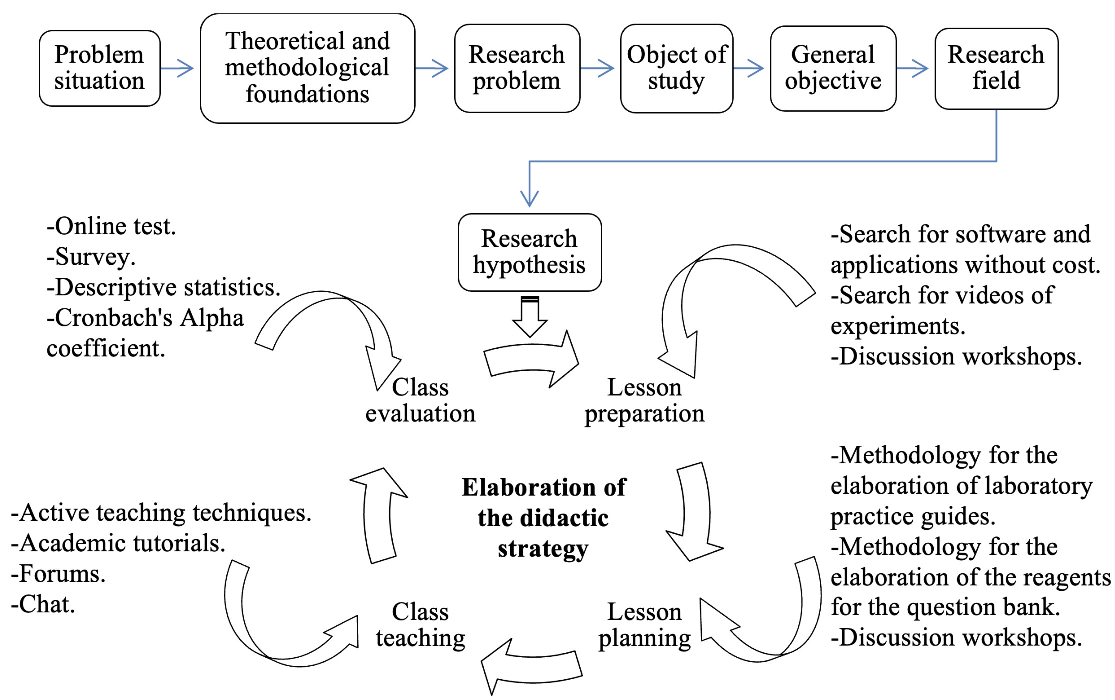

FIGURE 1. General diagram of the research methodology used.

The research was carried out at the Technical University of Manabí, Ecuador, in the ordinary academic period S1 2020 (which was developed virtually asynchronously, from June 2020 to October 2020), with the participation of six laboratory teachers (Teaching Technicians), seven teachers of 11 subjects belonging to the Department of Chemistry of the Faculty of Basic Sciences, taught in 13 third level careers. A total of 1,104 students from the first three levels of these careers participated, which were the total number of students enrolled in the subjects.

The didactic strategy was elaborated in four phases, namely: a) lesson preparation, b) lesson planning, c) class teaching, and d) class evaluation. To carry out each of these phases, the methodology shown in Figure 2 was followed.

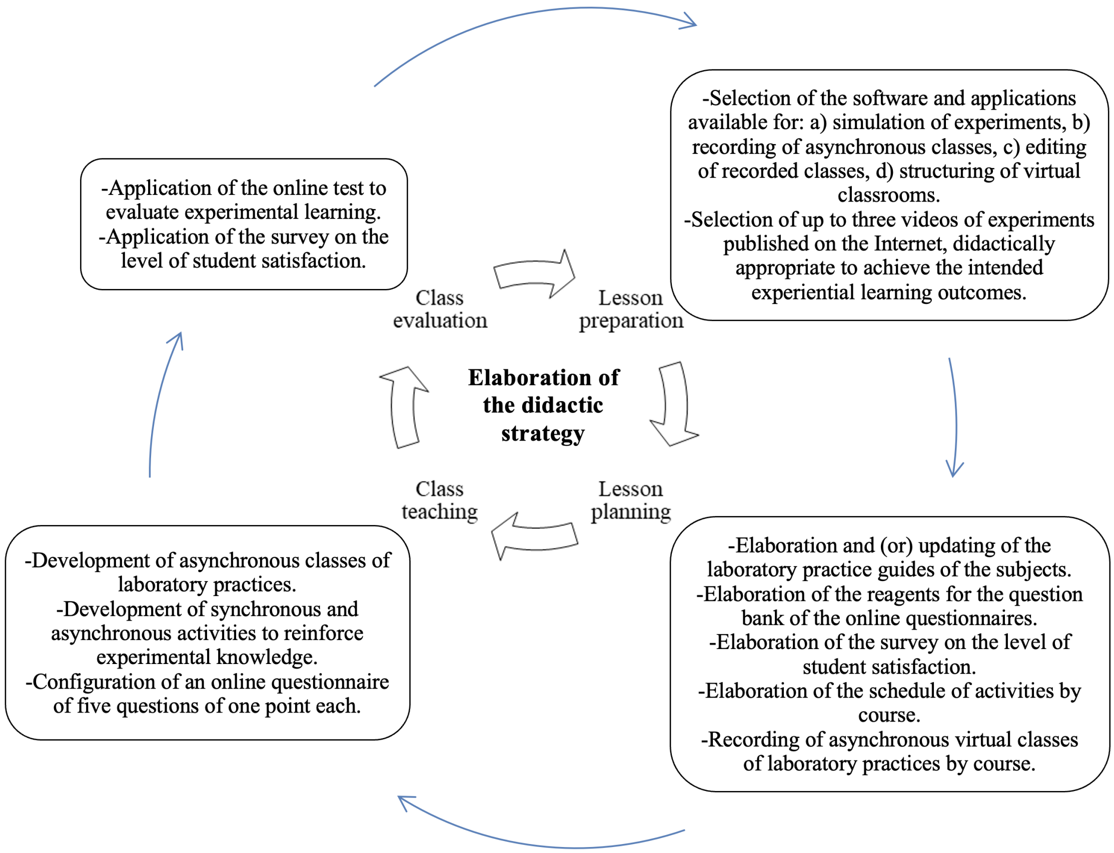

Figure 2. The methodology used for the development of the didactic strategy.

To carry out a systematic control of possible extraneous variables, in addition to fully applying the methodology described above, the following actions were developed:

1. In the laboratory practice guides, the procedures to be used in each of the practices were included, to avoid what is suggested by Ali and Ullah (2020), who refer those virtual laboratories do not provide any guidance on the procedure of an experiment.

2. The reagents for the Question Bank were elaborated taking into account the following criteria: 1) to have four answer options, 2) to evaluate only the experimental learning and 3) to respond to: i) the equipment, materials and reagents used in the practice (especially their function and way of handling), ii) the safety and protection measures (general and specific to the practice in question) and iii) the experimental procedure(s) used. This logic was followed in

order for the questions to assess mastery of laboratory techniques and skills, and the development of critical thinking and experimental design skills (Bruck, Towns & Bretz, 2010).

3. The asynchronous classes of each of the laboratory practices were elaborated considering three phases: initial (where the introduction of the class is made and the video observation guide of the virtual practice is explained), intermediate (where the video is presented) and the final (where a discussion on the experimental learning results of the practice is made).

4. The teaching-learning process of the experimental component was developed in three weeks for each laboratory practice, following the logic shown in Table 1.

Table 1. How the teaching-learning process of the experimental component was developed.

Weeks	Activity carried out	Form	Source	Directed by	Observations
Week # 1	Teaching of the laboratory class.	Synchronic	Zoom Meetings.	Teaching technician, under the guidance of the teacher of the subject.	It was recorded for students who could not attend.
Week # 2	Preparation of students for the evaluation.	Synchronic and asynchronous.	Zoom Meetings and Moodle platform.		Academic tutorials, forums and chat.
Week # 3	Application of the online evaluation.	Asynchronous.	Moodle platform.		Feedback was given in the same virtual classroom.

In order to favor the commitment, motivation and responsibility of the teaching technicians and subject teachers with the teaching-learning process of the experimental component, the didactic strategy was elaborated in a participatory manner, where everyone was involved in the three workshops carried out. This confirms Yukhymenko et al. (2021), who state that "... both knowledge and self-efficacy (a person's belief about his or her ability to perform a specific task successfully) play an important role in attitudes toward technology, including ease of use and usefulness, and behavioral intentions to use technology." (p. 2)

1. Before the beginning of the academic period, the teaching technicians and subject teachers were trained on the didactic strategy to be applied in the teaching-learning process of the experimental component, with emphasis on the implementation and evaluation of the academic results, with the objective that they would perceive that the ICTs that would be used are easy to apply to their teaching-learning process (ease of use) and that they would be useful for better student learning (perceived usefulness) (Yukhymenko et al., 2021).

2. In the first week of the semester, the technical teachers and the professors of the subjects conducted an induction to the students on the didactic strategy that would be applied in the teaching-learning process of the experimental component, which included the software and virtual platforms that would be used, with the objective

of leveling them and preparing them for the process, in terms of the way in which it would be developed and the skills they should have for the use of ICTs.

The following criteria were considered for the elaboration of the survey:

- Minimal effort by the respondent to answer it.
- Consistently and clearly worded questions, in a direct and affirmative manner, and with an adequate level of generalization and precision.
- Questions that are unbiased, concise, short, simple, and ask only one question.
- Appropriateness of the questions to the characteristics of the respondents.
- Logical sequencing of questions.

For the conception of the survey, we considered the proposal made by Sansón, Montagut and González (2002), who devised an organizational scheme to measure learning in the chemistry laboratory, which includes: 1) the quality and adequacy of the teaching materials, 2) the performance of the instructor, 3) the attitudes and motivation of the student, 4) the competencies achieved by the student in the performance of the laboratory work, and 5) the quality of the work produced by the student.

The data on class attendance, grades obtained by students and survey responses were collected in the virtual classroom, as established in the institutional regulations, through the resources provided by the Moodle platform for this purpose and through the evaluation system designed for this purpose. Once collected, these data were processed and analyzed, applying descriptive statistics (measures of central tendency, calculation of percentage values) and Cronbach's Alpha coefficient to determine the reliability and validity of the survey.

Results and Discussion

The strategy designed consists of four phases, as follows:

Phase 1. Lesson preparation

For the simulation of the laboratories, the software Virtual Lab Chem Collective was chosen because: i) it is an online simulation of a chemistry laboratory, ii) it helps students to link chemical calculations with real laboratory chemistry, iii) it allows students to select from hundreds of standards (aqueous) reagents and manipulate them in a way that resembles a real laboratory, iv) it is free, v) it provides information on physical and chemical properties of substances.

For the recording of asynchronous classes, the following applications were used: Zoom Meetings and Google Meet, because they: i) are free to make recordings of short or long duration, ii) were the most known and used by teachers and students, iii) are easy to use, iv) Zoom Meetings is easy to install, and Google Meet is an already installed application, v) optimize the size of the recording files.

The applications were used to edit the recorded classes: Camtasia, Ice Cream Video Editor, taking into account that: i) they create and produce quality videos without the need to be an expert in video editing, ii) they are intuitive, iii) they allow importing audio and video files in various formats in a simple way, iv) they have a free trial version, v) they allow adding text, animations and effects to the edited videos.

The Moodle platform was selected for the structuring of the virtual classrooms, with the different activities and resources, because in addition to being one of the most widely used platforms for this purpose, it is the one already used by the university where the research was conducted for these purposes, both at the undergraduate and graduate levels.

Phase 2. Lesson planning

In this phase, the necessary actions were programmed to develop the teaching-learning process of the experimental component of all the subjects taught by the professors of the Chemistry Department of the Faculty of Basic Sciences of the Technical University of Manabi. All the planning was carried out under the following principles:

1. Active participation of the professors of the subjects and the teaching technicians of the laboratories.
2. The laboratory practices were to be carried out after the conclusion of the content to which they responded by the professor of the subject. This is corroborated by Chan et al. (2021), who state that "...it is suggested that virtual chemistry laboratories are most effective when instruction is delivered close to the location of the learning content..." (p. 11).
3. Subject practices were to be assigned to the teaching technicians in the laboratories, according to affinity to their fields of training.

The planned activities were as follows:

- The schedule of laboratory practicals was developed, in conjunction with the subject teacher, which was published in the virtual classroom in the corresponding tab. Four practical's laboratories were carried out for each subject taught in the field of chemical sciences.
- The guides for the laboratory practices of the subjects were prepared and (or) updated. The quality required in the development of these guides, according to the methodology established for this purpose, contributed to improving the effectiveness of experiential learning.
- Virtual classrooms were structured on the Moodle platform (Figure 3). In these virtual classrooms the professors of the subjects enter as guests.
- The study materials were selected in different formats for each of the laboratory practices. This was done collaboratively among the teaching technicians, under the supervision of the subject teachers.
- Study guides were prepared for each of the laboratory practices, to guide students on how they were to perform the experimental learning activities autonomously.

- Twenty multiple-choice questions were elaborated for each laboratory practical for evaluation, strictly following the criteria established for its elaboration, for the bank of questions used for the online questionnaire.

- Asynchronous class of laboratory practices were recorded and edited by the teaching technicians, under the guidance of the subject teachers.

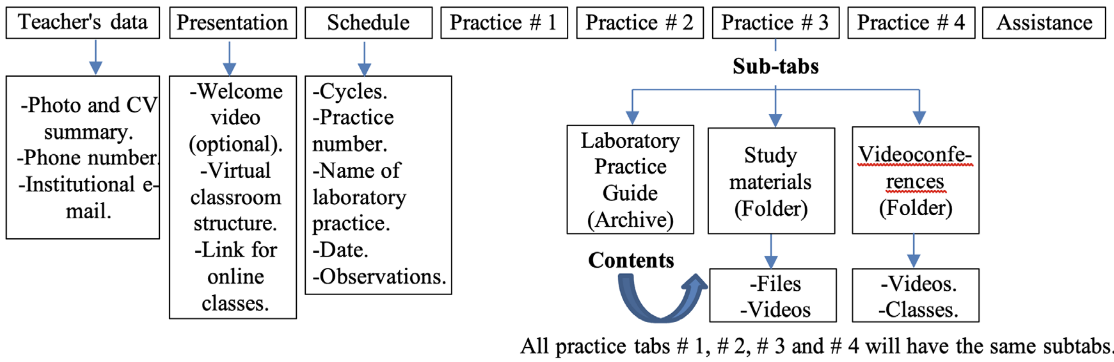

Figure 3. Structure of the virtual classroom for the experimental component.

Phase 3. Class teaching (implementation of planned activities)

- The asynchronous classes of each of the planned laboratory practices were carried out.

- The planned synchronous activities (academic tutorials) were carried out through Zoom Meetings and Google Meet.

- Asynchronous activities (forum, chat) were carried out through the virtual classroom and other communication channels, for example: WhatsApp.

- The online evaluation of each of the laboratory practices was configured in the virtual classroom. This evaluation has five questions of one point each, which are randomly chosen from the 20 questions that appear in the question bank for that practice.

Phase 4. Class evaluation (assessment of the results)

Once the online evaluation, on the function and handling of the equipment, materials and reagents used in the practice, the general and specific safety and protection measures and the experimental procedure used, was applied to the students, which lasted 20 minutes, two weeks after the asynchronous class was taught by the lab teacher, the results are as follows:

The percentage of students who attended the academic activities of the experimental component in OAP S1 2020 (which was developed virtually asynchronously, from June 2020 to October 2020) is very similar to that achieved in OAP S2 2019 (which was developed face-to-face, from October 2019 to February 2020), as values of 88.6 percent and 88.3 percent were obtained, respectively. Student attendance was monitored through the completion of the planned evaluative activities. It is considered that this was due to the fact that regularly in the on-site academic periods, between 10 and 15% of students withdraw from the careers, without cancelling their enrollment, due to lack of motivation and vocation towards them, for not having received an adequate orientation and vocational training, especially in high school.

This corroborates that in the OAP S1 2020, which was developed in an asynchronous virtual form, a very similar number of students did not participate in the experimental component, in percentage terms, so the change of modality in the teaching-learning process of that component did not influence this aspect. Most of the withdrawn students were in the subject General Chemistry I, which is taught in the first semester of the degree courses.

Table 2 shows the measures of central tendency (mean, median and mode) of the grades obtained by the students and the percentage of them passed by subject, in the OAP S1 2020.

Table 2. Measures of central tendency of the grades obtained and the percentage of students passed in the virtual teaching of chemistry laboratories by subject.

Subjects	Qualifications obtained			Students approved (%)
	Mean	Median	Mode	
Physicochemistry	9.2	10	10	93.8
Chemistry	9.0	9	10	95.5
Organic Chemistry I	8.5	9	9	90.5
Organic Chemistry	8.5	9	9	88.9
Analytical Chemistry	8.4	9	10	89.0
Organic Chemistry II	8.1	9	9	82.6
Applied Chemistry	7.8	8	10	73.7
Inorganic Chemistry	7.7	8	10	79.5
General Chemistry II	7.7	8	8	76.7
Environmental and Ecological Chemistry	7.6	8	9	78.0
General Chemistry I	7.3	8	8	70.3
Total	**7.8**	**8**	**9**	**77.7**

During this period, an average score of 7.8 points out of a possible 10 was achieved by the enrolled students; that is, 78.0 percent of the total. Compared to the previous semester, the average score increased by 4.4 percent, despite the fact that in the teaching-learning process of the experimental component in the classroom, some fewer demanding indicators are evaluated, such as attendance to the laboratory practice, the group report of the practice performed. This corroborates Chan et al. (2021), when they refer that "...very little evidence has been found that virtual labs perform worse than hands-on labs." (p. 10) They further state, "Virtual labs can provide better results in learning outcomes ... than traditional passive media and are considered equally effective and sometimes better than actual hands-on labs." (p. 12)

This result coincides with the results achieved by Tsai, Ho & Nisar (2021) in their research, who demonstrated that with the application of a virtual laboratory, students improved their experimental learning with respect to those who developed the laboratory practices in a conventional, face-to-face manner. These results are probably positively influenced by factors related to the teaching methodology used by laboratory professors, their mastery of the use of ICTs in university educational processes, the diversity of technologies used, the didactic quality of the materials of all types developed, among others.

Likewise, the percentage of students approved in OAP S1 2020 is 5.3 % higher than that achieved in the previous period, which was 72.4 %, when the experimental learning was carried out face-to-face, which corroborates what was stated by Chan et al. (2021).

In the subject General Chemistry I, the students achieved the lowest average grade (7.3), and the lowest percentage of students passed the experimental component (70.3 %), due to the fact that this subject is taught in the first level of the careers, and the students have difficulties with previous knowledge of the basic contents of this subject, and most of them had not previously carried out laboratory practices, or very few of them had done so.

A similar analysis was performed with the grades obtained by students for each career, in the OAP S1 2020 (Table 3).

Table 3. Measures of central tendency of the grades obtained and the percentage of students passed in the virtual teaching of chemistry laboratories by career.

Careers	Qualifications obtained			Students approved (%)
	Mean	Median	Mode	
Pedagogy in Experimental Sciences with mention in Mathematics and Physics	9.0	9	10	95.5
Nutrition and Dietetics	8.6	9	10	92.5
Agro-industrial Engineering	8.3	9	9	88.2
Pedagogy in Experimental Sciences, mention in Chemistry and Biology	8.2	9	10	84.2
Chemical Engineering	8.1	9	9	83.2
Clinical Laboratory	7.8	8	10	73.7
Aquaculture Engineering	7.7	8	10	75.0
Industrial Engineering	7.5	8	9	75.1
Agronomy Engineering	7.5	8	9	72.4
Agricultural Engineering	7.5	8	10	70.6
Electrical Engineering	7.1	8	8	67.9
Mechanical Engineering	6.8	7	8	62.6
Zootechnical Engineering	6.6	7	6	50.9
Total	**7.8**	**8**	**9**	**77.7**

Students in Electrical Engineering, Mechanical Engineering and Zootechnical Engineering obtained the lowest grade point averages (≤ 7.1) and less than 70% of them passed the experimental component of the chemical science subjects they received. It is thought that this is due to the fact that students enrolled in these careers tend to have little motivation to learn chemistry, considering it of little importance for their future careers.

The survey applied has a high reliability and validity, since the Cronbach's Alpha coefficient calculated was 0.968. The survey was answered anonymously and virtually by 980 students, 88.8% of the total number of those who participated in the teaching-learning process of the experimental component. The results of the survey applied to the students are listed in table 4.

#	Questions	A.F[a]	R.F[b]
1	Do the activities or contents presented in the virtual classroom maintain an adequate order or sequence?	972	99,2
2	Do the lab practicum guides, study materials and video lecture uploaded in the virtual lab classroom for the practicum fully relate to the contents and objectives of the practicum?	967	98,7
3	Are the laboratory practice guides, study materials and videoconference uploaded to the virtual classroom easy to understand and did they help your learning?	933	95,2
4	Was the appropriate time given for the completion of the activities proposed in the virtual classroom where the experimental component is shared?	924	94,3
5	Do you find the structure established in the virtual laboratory classroom adequate and clear?	925	94,4
6	Did the topics covered in the course meet your academic expectations with respect to laboratory practices?	930	94,9
7	Do you consider that the information in the study guides is relevant to the understanding of the objective of the practice?	941	96,0
8	Do you consider it appropriate to receive the experimental component asynchronously?	734	74,9
9	Did you find the video explaining the practice adequate and with the necessary information?	942	96,1
10	Are you satisfied with the quality of the asynchronous activities performed by your lab teacher?	936	95,5
	Overall average		**94,2**

Table 4. Absolute and relative frequency of positive responses to survey questions. [a] Absolute frequency, [b] Relative frequency.

These results confirm their satisfaction with the quality of the teaching-learning process of the experimental component in the OAP S1 2020, since 94.2 percent of the students, on average, responded positively to the 10 questions asked in it (Table 4). Chan et al. (2021) refers that "...comparative studies suggest that virtual chemistry laboratories are equally effective or sometimes better than hands-on laboratories with respect to declarative knowledge, procedural knowledge, and skill-based outcomes." (p. 10) In Tsai, Ho & Nisar's (2021) research, the authors corroborated those students had high levels of satisfaction with the use of the virtual chemistry lab they implemented, and that they preferred virtual labs over conventional labs.

Percentages higher than 94 percent were obtained in almost all the questions of the survey, which corroborates that:

- The activities or contents presented in the virtual classroom had an adequate order or sequence, and their structure was appropriate and clear.

- The laboratory practice guides, study materials and videoconferences uploaded in the virtual laboratory classrooms for the practices, were totally related to the contents and objectives of the practices, were easy to understand and aided learning, and their information was relevant to the understanding of the objective of the laboratory practices. This corroborates Chan et al. (2021), who refer that, "...students learn procedural knowledge and laboratory skills in virtual environments.../ Especially when procedural guidance was provided during the virtual experiment, students were able to perform better..." (p. 10) Tsai, Ho & Nisar (2021) found that students showed satisfaction with the design of the teaching materials and the convenience of handling the virtual laboratory with clear and concise instructions.

- Appropriate time was given for the completion of the proposed activities, and lab teachers responded adequately and promptly, to messages or concerns raised in the virtual classrooms by students, thus avoiding the caveat made by Russell and Weaver (2011), when they said that "students often fail to achieve the technical advances that should be possible during their laboratory work...due to a disconnect between students and instructors in terms of laboratory goals and purposes." (p. 57).

- The topics covered in the course met the academic expectations of the students with respect to the laboratory practices and the students are satisfied with the quality of the asynchronous activities carried out by their laboratory professor.

The teachers interviewed in the research conducted by Tsai, Ho & Nisar (2021), posited that virtual experiments can be conducted in a simple, clear and safe way, through them, knowledge related to experiential learning can be imparted more effectively, and it allows students greater concentration and attention in classes, and more motivation for learning, all of which contribute to improving the effectiveness of experiential learning for them.

A total of 74.9 percent of the students considered adequate to receive the experimental component in an asynchronous virtual form. Similar results were obtained Reyes et al. (2021) in their research. On the other hand, Mutlu and Sesen (2020) corroborated those students who received experimental teaching through virtual laboratories showed a better attitude towards chemistry, since they showed greater interest in it, greater understanding and learning and highlighted the importance of chemistry in real life. They also revealed to be more satisfied with the evaluation and cooperative learning that the virtual laboratory allows.

This confirms to some extent the correct strategy adopted to maintain the teaching of chemistry laboratories under pandemic conditions, taking into account the complexity of experiential learning of chemical science subjects under the virtual modality. So that the didactic strategy applied is considered an educational innovation and a contribution to knowledge, on how to develop the experimental learning of Chemistry in a virtual way, of which there is no evidence that it has been applied before elsewhere, at least, in the way it was conceived in the present research.

The effectiveness of the application of virtual experiments to contribute to the experimental learning of students was demonstrated in this research, and we are certain that if we have a complete virtual laboratory that is contextualized to the contents of the subjects, as well as intensified teacher training, we could overcome the challenges identified and, thus, further improve the experimental teaching-learning process of chemistry; however, virtual experiments should not and cannot totally substitute for face-to-face experimental learning in laboratories, because the skills of manipulation of equipment, materials and utensils are only achieved in a chemical laboratory when the student, for example, measures a mass with an analytical balance, measures a volume with a pipette or test tube, measures the acidity with a pH meter, measures the density of a substance with a pycnometer, just to cite a few examples.

A good option would be to develop experimental learning in a hybrid way; that is: virtual experiments for those practices that demand it due to their characteristics and demands, and experiments in chemical laboratories, for those practices that allow it, because they do not imply risks for the students' health and there is enough equipment, materials and reagents to carry them out. This could constitute a new line of investigation for researchers.

Conclusions

The 11.4 percent of students withdrawn in the evaluated semester (virtual) was similar to the 11.7 percent of learners withdrawn in the previous academic period (face-to-face), which corroborates that the virtual modality used in that semester did not influence student retention.

The average grade of the students in the evaluated semester (virtual) of 7.8 points out of 10 possible; that is, 78.0 percent of the total, higher by 4.4 percent than the previous period (face-to-face), corroborates the effectiveness of the didactic strategy applied for the teaching of the experimental component of Chemistry in the virtual modality.

The academic results and the applied survey corroborated that the quality of the teaching-learning process of the experimental component in the evaluated semester was good, due to an adequate planning, organization, implementation and evaluation of the applied didactic strategy, which allowed the students to achieve the experimental learning results foreseen in each laboratory practice.

The dissemination of the results of this research will contribute to the increase of scientific knowledge on the virtual experimental learning of Chemistry and will open new fields of research on this subject. However, in the future, in the face of similar situations that require the development of experimental learning of chemical science subjects virtually, it is suggested that the institution could have a more complete virtual laboratory to avoid using several of them and that teachers be trained in the edition of recorded classes and in the use of the selected laboratory, their preparation in virtual learning environments is prioritized, as well as to enhance their collaborative work. It is also important that students have access to the Internet, the technological equipment they have, the environment where they carry out their learning activities, to avoid distractions, lack of concentration and attention, among others.

Conflict of Interest

The author(s) declare(s) that there is no conflict of interest.

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