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Compilation of Chemistry Experiments for an Online Laboratory Course: Student's Perception and Learning Outcomes in the Context of COVID-19

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Abstract: The COVID-19 pandemic forced a quick change of the teaching styles to online lessons; specifically, experimental classes had to be redesigned to achieve the best possible academic performance within the imposed limitations. This work describes three different approaches: adaptation of a laboratory chemistry course to an online mode, learning proficiency, and students' perception. First, a compilation of experiments that cover topics from general chemistry at an undergraduate level was included, with activities that can be conducted employing daily-use materials and substances. Next, the learning achieved was estimated, and the grades were related to a domain level of competency acquisition. The results indicated that at least 68% accomplished the highest level. Finally, the perception of the participants about the activities was inquired. The statistical analysis showed a generalized positive attitude towards the mode proposed, an appreciation of having earned meaningful knowledge, and most of the students stated they would recommend the course.

Keywords: educational innovation; COVID-19; higher education; professional education; remote learning; online teaching; chemistry laboratory; hands-on experiments; competencies; students' perception

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1. Introduction

The health contingency originated by the COVID-19 pandemic posed a worldwide challenge, as emerging strategies had to be sought to continue with essential activities safely [1]. In academia, it raised the need to redesign the classes. Moreover, it led to a sudden shift from in-person to online sessions or e-teaching [2] through interactive platforms, such as Zoom (zoom.us (accessed on 2 December 2021)) [3], Skype™ calls, or Microsoft® Teams; incorporating new technological resources to avoid affecting academic performance [4], while trying to keep a motivating and encouraging environment [5].

Teaching during a disruption requires creativity, flexibility, and resilience; and learning during this time requires similar skills [6]. While the students should want to learn, the teacher must not be limited to communicating information in a traditional way but should take risks to guide them to the production of knowledge [7], for instance, by creating new situations that stimulate their learning and give meaning to the knowledge acquired [8–10]. It has been proven that if leaders show a positive attitude towards the usefulness of online teaching, they may constructively influence the students' behavior and perception [11].

The relevance of experimental work in chemistry is undeniable [12]. In general, laboratory experiences have the following goals: understanding scientific concepts, developing practical skills and problem-solving abilities, stimulating scientific thinking, and motivating a general academic interest, among others [13]. These objectives correspond to the cognitive, affective, and psychomotor domains that are founded on meaningful learning [14,15].

In this field, whereas for theoretical subjects, it was complicated to integrate students and leaders into an e-teaching system [16], it represented an even greater challenge for experimental disciplines [17]. Some of the major concerns that emerged were how to incorporate experiments without compromising the educational goals and how to stimulate the acceptance towards this mode [13,18]. One more focal point was how to digitally maintain student–student and student—instructor interactions since these are crucial components of the learning process.

In this transition, simulators, remote-controlled laboratories, video-based experiments, and other digital tools have been integrated into these online courses [19,20]. Although these resources may be excellent complements, effective learning needs to be strengthened through authentic and research-based experiences [21].

In the literature, there are several original cases regarding the adaptation and innovation of in-person experimental sessions towards an online mode. Selco [22] proposed a virtual chemistry course during the pandemic using food, household substances, and chemicals available in stores (such as baking soda, antacid, and aspirin) to cover acid–base, precipitation reactions and crystal growth, and exothermic and endothermic processes. The author reported that in the change from face-to-face to distance classes, it was essential to be flexible with the resources that were easily available to carry out experiments at home. This is consistent with other publications that state that good online practices depend heavily on the organization and that the instructor should stimulate a friendly environment, provide clear guidelines, and find ways to connect with students despite the remote connection [11,23].

Al-Soufi et al. [24] described the design and construction of a double-beam photometer using smartphones and domestic materials for Applied Thermodynamics, using wine as dye and kitchen paper as filter paper. Another proposal, which started a few months before the lockdown, was the "The Chemical Kitchen" (TCK) initiative at Imperial College London [25], where a domestic kitchen serves as a scientific laboratory, and the project aims to develop practical skills and competencies, such as collaborative teamwork and scientific thinking. A different example is presented by Bruce et al. [26], in which chemistry kits were assembled by a faculty team and distributed through a rental program at the university bookstore, providing access to the experiment.

Schultz et al. [27] reported hands-on experiences about colligative properties and acid-base reactions conducted in a kitchen; the authors mentioned that the at-home activities added situations that only take place in the laboratory (such as spills and cleanup) and that may not be imitated by any virtual tool. A similar conclusion was reported in Kelley's study [21], where it is stressed that scholars prefer running hands-on experiments over video assignments. Moreover, it is concluded that the interest and morale seemed to be higher with these implementations, and the learning process is similar to the techniques in in-person sessions.

After pondering on the educational needs and how to provide continuity to the curricular plan, appropriate conditions to create an online laboratory were settled. Accordingly, the present work describes a selection of experiments related to a laboratory of general chemistry at an undergraduate level. While the core is non-dangerous procedures using several substances and materials of daily use; it also incorporates free interactive simulators and demonstration videos. Not having the equipment, materials, and reagents that are normally available in a laboratory was not viewed as a limit but an opportunity to look for other ways to meet the learning objectives and to develop skills and abilities. Furthermore, the situation promoted creativity since the only restriction was the domestic nature of the materials. These actions are meant to encourage interest in chemical experimentation, despite social isolation.

To genuinely consider the impact of chemistry lessons, the effectiveness of the proposal was analyzed in terms of competency acquisition, which is related to the gain of knowledge.

The execution of this task does not follow a specific method, and it becomes a complicated exercise; however, this can be successfully accomplished by performing a continuous assessment of activities (e.g., bibliographic research, problem-solving, at-home experiments, quizzes involving real cases solved through argumentative thinking) focused on promoting distinctive skills. The present work agrees with the recent research published by Mínguez-Aroca [28], where the connection of the activities performed and the competencies to be achieved are discussed.

Despite the virtual chemistry courses that have already been organized [24,25,29,30], little research has been published related to what is more valuable for the students, what are their format preferences, and what is their general perception after taking these online classes. Therefore, this study is based on the following research questions:

RQ1. *How to adapt a competency-based chemistry laboratory course to an online mode?*

RQ2. *How is the students' learning favored after completing an online laboratory course?*

RQ3. *What are students' perceptions after performing chemistry laboratory experiments with daily-use materials and substances?*

2. Materials and Methods

2.1. Overview

The present study consists of two parts. In the first one, a selection and implementation of an adequate sequence of at-home experiments that may be conducted with safe materials that are easy to collect is described. This was assembled to fulfill the competencies specified in the academic programs of two experimental chemistry courses (Chemical Experimentation and Statistical Thinking I & II, identified as Q1021 and Q1023, respectively) of the curriculum map of some engineering degrees at the Tecnologico de Monterrey in Mexico. Additionally, the proposal was designed to generate an authentic experimental work environment, where the activities were not limited to a typical theoretical or purely demonstrative format.

The second part describes the analysis of the learning outcomes and the perspective of the students. Regarding the educational aspect, the final grade of the course was related to a domain level of competency acquisition, as reported in [31]; also, the improvement of the students' performance after completing the programs was assessed. Then, the perception related to the experiments was explored by applying surveys monitoring the learners' previous background with online laboratories, their expectations, and their sense of accomplishment at the end of all the sessions. The answers provided were statistically treated and analyzed, considering the evidence of associations between the learning quality and the perceptions described by the CEQ (Course Experience Questionnaire) scales [32–34].

2.2. Participants

This research was conducted using a quasi-experimental design with conventional non-probability sampling [35]. It involved 194 students between 18 and 21 years old, 57% male and 43% female, and they all agreed to be part of this work. They were enrolled in the second semester of different engineering degrees at two different campuses of the Tecnologico de Monterrey. From this population, 150 attended Q1021 and were separated into 7 groups from 12 to 29 members; and 44 were registered in Q1023 and distributed into 2 groups of 21 and 23 elements, respectively, where each group was supervised by one teacher.

The students' distribution by degree is summarized in Table 1. It should be noted that Q1021 is a course for all engineering degrees, but Q1023 is just mandatory for degrees that have a chemistry approach.

Table 1. Distribution of students' population by engineering degree in the courses Q1021 and Q1023.

Course	Degree	%
Q1021	Biomedical Engineer	1
	Biotechnology Engineer *	23
	Chemical Engineer *	9
	Civil Engineer	3
	Electronic Engineer	1
	Food Engineer *	1
	Industrial and Systems Engineer	23
	Industrial Physical Engineer	5
	Innovation and Development Engineer	6
	Mechanical Engineer	8
	Mechatronics Engineer	8
	Nanotechnology Engineer *	5
	Sustainable Development Engineer *	7
Q1023	Biotechnology Engineer *	48
	Chemical Engineer *	23
	Nanotechnology Engineer *	20
	Sustainable Development Engineer *	9

* Engineering degrees with a chemistry approach.

2.3. Course Description

The implementation was made in two sequential chemistry laboratory courses, "Chemical Experimentation and Statistical Thinking I (Q1021)" and "Chemical Experimentation and Statistical Thinking II (Q1023)" [36,37]. Each is taught in five-week periods, according to the educational model Tec21 of Tecnologico de Monterrey [38], which has a competency-based learning approach. This system has shown to be effective in different formats, such as "i-Semester" [31]; several science subjects [39,40]; and in the challenge-based learning methodology [41–43], which is a key collaborative transversal strategy in this program.

Both courses may be equivalent to a one-semester program of general chemistry laboratory; and consist not only of conceptual topics, specified in Table 2, but also, of procedural and attitudinal aspects. Among the procedural aspects, there are carrying out experiments, applying principles, and building arguments to explain the behavior of natural phenomena, and effectively communicating results and conclusions. Some of the most noticeable attitudinal contents are demonstrating proactivity in the search for new knowledge, understanding the relevance of the scientific method to prove or disprove explanations of natural phenomena, and identifying the importance of chemistry to understand daily-life situations.

Table 2. Academic content of the courses Q1021 and Q1023.

Q1021	Q1023
• Safety standards and laboratory equipment • Statistical analysis • Experimental determination of properties of matter, according to its chemical nature and physical state • Chemical bonds • Polarity of molecules and their relationship with solubility and conductivity • Solutions and colligative properties • Basic concepts of reaction rate and implementation of oxidation-reduction reactions in the construction of batteries (electrochemistry)	Statistical analysis of experimental data Stoichiometry Introduction to chemical equilibrium Acid–base equilibrium Kinetic control of chemical reactions

Based on the information published by the Tecnologico de Monterrey [34,35], the aim of the curriculum objectives is to develop the following institutional competencies (IC):

IC1. Explain and demonstrate the behavior of natural phenomena through argumentations based on concepts, theories, and principles.
IC2. Assess the components that integrate a case study; make decisions to solve them; and implement actions, applying current standards and considering environmental care, to solve real engineering and science problems.
IC3. Apply fundamental chemistry concepts of the structure and function of matter through procedural competencies and analyze statistical data obtained from experiments.

3. Experimental Sessions

The role of the teacher is fully reflected in RQ1, which refers to the adaptation of a competency-based chemistry laboratory course to an online mode. Specifically, the actions involved in the design started by reviewing the official curriculum goals and the intended learning outcomes; looking for activities related to the relevant topics that could be performed using daily-use substances and materials; and then preparing guidelines to conduct the experiments listed in Table 3.

Table 3. Experimental sessions for the courses Q1021 and Q1023.

Course	Topic
Q1021	3.1. Chemistry Laboratory Safety 3.2. Common Laboratory Equipment and Experimental Measurements 3.3. Separation of Mixtures 3.4. Preparation of Solutions and Dilutions 3.5. Redox Reactions 3.6. Electrochemical Cells
Q1023	3.7. Stoichiometry by Precipitation Reactions 3.8. Chemical Kinetics 3.9. Chemical Equilibrium 3.10. Acid–base Titration

Each session was 2 h long and was held twice a week. During this time, the teacher was in charge of briefly explaining the procedures and supervising the performance. The students were separated into virtual rooms where each team carried out the assigned activities in real-time, and they could ask for advice at any moment. In case someone had Internet connection issues or was not able to gather the necessary materials, it was enough if only one team member performed the experiment and the rest of the classmates would participate by giving instructions, recording the measurements, and writing the observations among others. Afterward, they had one week to prepare a report that contained a concise literature review regarding the state-of-the-art, the description and discussion of the trials and results, and conclusions. The instructor was able to assess the understanding of the concepts by analyzing the work and providing formative feedback.

3.1. Chemistry Laboratory Safety

To prevent accidents in a laboratory, it is necessary to know the safety measures, for example, recognizing warning signs and emergency exits; identifying the code color for each supporting service; and locating emergency showers, eyewashes, and safety equipment. The Official Mexican Standard NOM-018-STPS-2015 establishes the requirements of the Global Harmonized System or GHS for the identification and communication of dangers and risks due to chemical substances [44].

To reinforce the safety measures, labels according to GHS standards for two chemicals provided were schemed; these included H-phrase codes on health hazards and P-phrases indicating precautionary advice [45]. Then, each team wrote a guideline of good practices, including ten basic safety measures for a chemistry laboratory (Figure 1); and looked for the meaning of 10 different pictograms related to safety and chemicals management. Finally, they were asked to (1) identify the code color used for gas, water, and vacuum pipes according to Mexican Standards; (2) research the conditions to use fire extinguishers, safety showers, and eyewash stations; and (3) investigate the characteristics of a proper ventilation system.

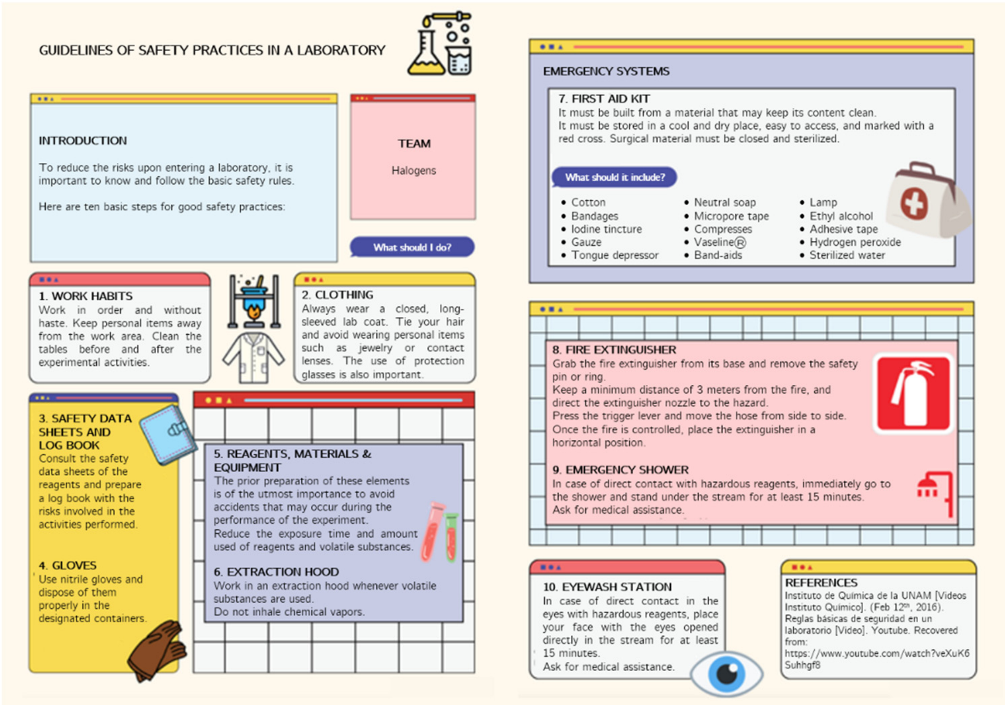

Figure 1. Example of a guideline of safety practices in a laboratory (Image translated from a students' report).

3.2. Common Laboratory Equipment and Experimental Measurements

Experimental work is an excellent activity to introduce scientific concepts and promote procedural skills. One of the first steps may be the identification of common equipment and its proper use. Although in distance learning, there is no actual manipulation of laboratory devices, it is relevant to become familiar with the common instruments. A demonstration video [46] with a brief explanation about the use of some instruments was presented. In addition, an interactive website was used to reinforce the identification of common equipment [47]. Several instruments shown were classified according to their use with the information provided and by conducting bibliographic research.

Next, learners estimated the uncertainty of the measurement of different instruments used at home, such as spoons and cups, by applying the concept of error equal to minimum scale/2. As a complement, on an interactive page [48], the determination of uncertainties in volume measurements was exercised. Finally, a teamwork task was carried out (Figure 2), where the number of drops contained in one milliliter of water measured with a syringe was counted [45]. The data collected was used to estimate basic statistical parameters (mean and standard deviation) of a set of direct measurements and concepts, such as accuracy, precision, and experimental error were applied and discussed.

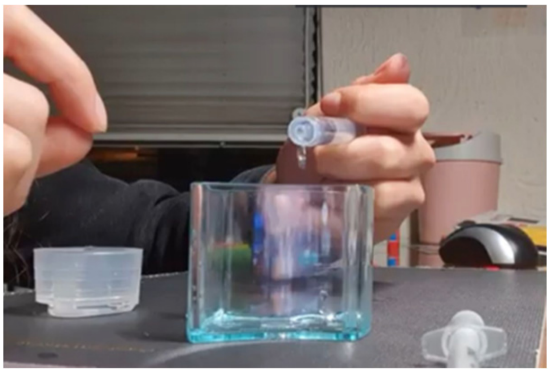

Figure 2. Drop counting activity using a syringe (Image extracted from a students' report).

3.3. Separation of Mixtures

The separation of mixtures is a common technique used in general chemistry to isolate the components; the procedure applied is based on the physicochemical properties of substances. A mixture of ethanol, sugar, and oil (mixture A) and a second one formed by table salt, sand, and screws (mixture B) were separated, considering the characteristics of each component [45]. This trial was similar to the one described by Schultz et al. [27].

The separation procedures are outlined below (Figure 3):

- Mixture A: ethanol and oil were separated from the sugar by filtrating the sample using a funnel (or a homemade funnel built with the top part of a plastic bottle) and a coffee filter. Subsequently, the ethanol was separated from the oil by decantation.
- Mixture B: screws were removed from the mixture of table salt and sand with the help of a magnet. Then, water was added to the mixture to dissolve the table salt so that filtration could be ulteriorly used to separate the sand from the dissolved table salt. Finally, the solution was heated to evaporate the water and recover the table salt.

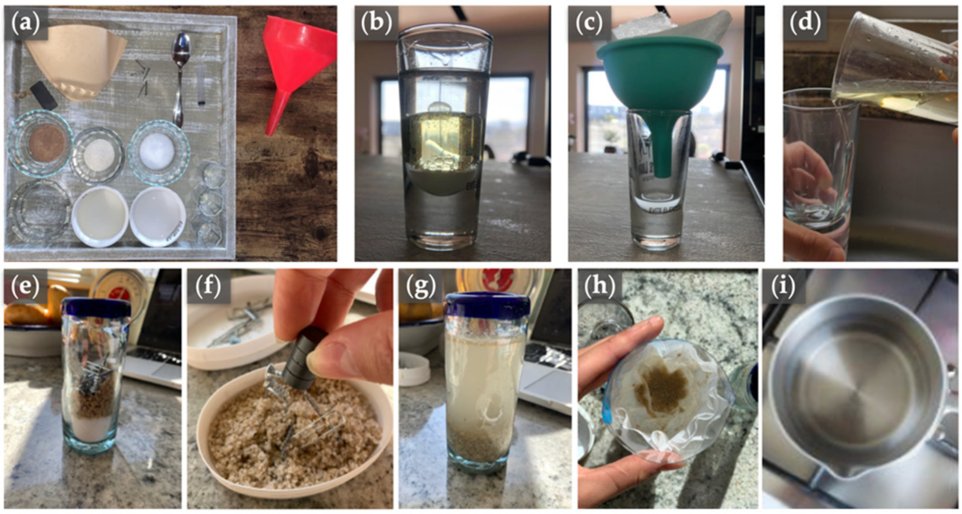

Figure 3. (**a**) Components of mixtures A and B and materials used, (**b**) mixture A, (**c**) separation of sugar from ethanol and oil by filtration, (**d**) separation of ethanol and oil by decantation, (**e**) mixture B, (**f**) separation of the screws by magnetization, (**g**) dissolution of table salt, (**h**) filtration of sand to recover the saline solution, and (**i**) evaporation of water to recover the table salt (Images extracted from a students' report).

3.4. Preparation of Solutions and Dilutions

The preparation of a solution of known concentration is perhaps the most common activity in a laboratory. While pipettes and volumetric flasks are the preferred materials when the concentration needs to be accurate, to teach how to prepare aqueous solutions and dilutions, syringes, kitchen scales, measuring cups, and spoons were employed. The following solutions were prepared:

- A 0.025 molal dilution of table salt in 0.25 kg of water was prepared using a measuring cup as a container. Considering the solute was only sodium chloride (NaCl), 0.36 g or 2 teaspoons of NaCl were dissolved in 250 mL of tap water (assuming 1 teaspoon weighs approximately 0.2 g).
- A cup of coffee was prepared with 0.4 g of instant coffee and 1.2 g of common sugar, assuming it was sucrose ($C_{12}H_{22}O_{11}$), and 250 mL of tap water. This solution was furtherly diluted 1000 times, taking into account only the sucrose concentration since the coffee was used just to add color to the sample [49]. This process was performed in 3 steps (Figure 4).

Figure 4. Sucrose solutions diluted 1000 times using coffee as colorant (Image extracted from a students' report).

Finally, a virtual simulator [50] was used to practice the procedure and the calculations to prepare 5 different solutions of molar concentration.

3.5. Redox Reactions

Oxidation and reduction procedures are very common in many daily activities and biochemical processes; as examples, two sequential redox reactions were executed [51]. The first part consisted of the oxidation of galvanized nails with zinc coating by adding iodine tincture; this substance was directly purchased at the pharmacy. First, a handful of small nails was placed inside a container, and enough iodine tincture was added to cover them; at least one nail was kept in its original form to use as a reference. As a water bath, enough tap water was poured into a metal vessel to at least cover the height of the container with the nails and the iodine tincture. The sample was moderately heated for around 15 min to speed up the reaction process but without boiling it. Because the iodine tincture contains alcohol, it was important to avoid direct contact with the fire, and the container was covered to prevent the alcohol from evaporating. When discoloration in the solution due to iodide formation was observed, the heating was stopped, and the solution was left to cool for a few minutes. Afterward, with the help of a cloth or gloves, the container was removed from the water bath and the iodide solution was transferred to another glass container to observe the final oxidized material (Figure 5).

In the second part, the colorless iodide solution obtained in the previous procedure was oxidized. To this end, about 5 mL of laundry bleach (5–6% NaOCl) were poured with the help of a syringe (or dropper), and then 5 mL of vinegar (5% CH_3COOH) were added, which led to the original color of the iodine solution after the oxidation.

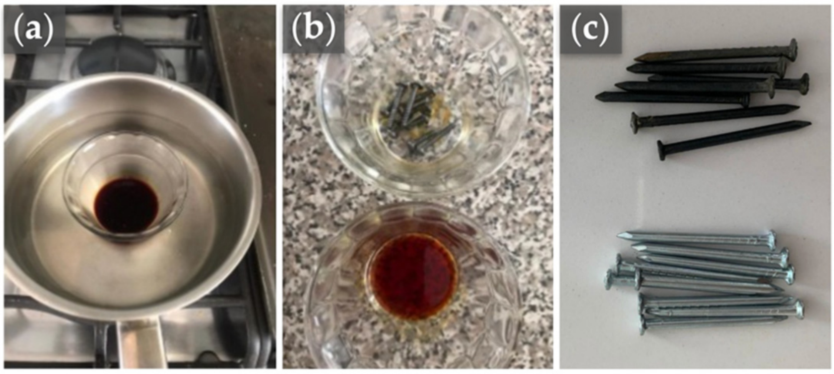

Figure 5. (**a**) Heating the mixture of nails and iodine tincture in a water bath. (**b**) Separation of the iodine tincture and nails after the reaction. (**c**) Comparison of the nails before and after the oxidation reaction (Images extracted from a students' report).

3.6. Electrochemical Cells

During the lockdown, homemade materials to create and measure electrochemical cells [52] were difficult to collect; the teacher made a demonstrative assembly of two galvanic cells, Zn–Cu and Mg–Cu, and recorded a series of potential measurements analyzed with statistical calculations. Students were asked to compare the calculations with the theoretical values obtained using a simulator [53]. From this information, it was established whether the device represented a galvanic or an electrolytic cell, and the spontaneity of different redox reactions was concluded. Alternatively, everyone who had access to a voltmeter and either alligator clips or copper wire was able to build a cell using an aluminum can, graphite from a pencil as electrodes, and a saturated saline solution as electrolyte [54] (Figure 6).

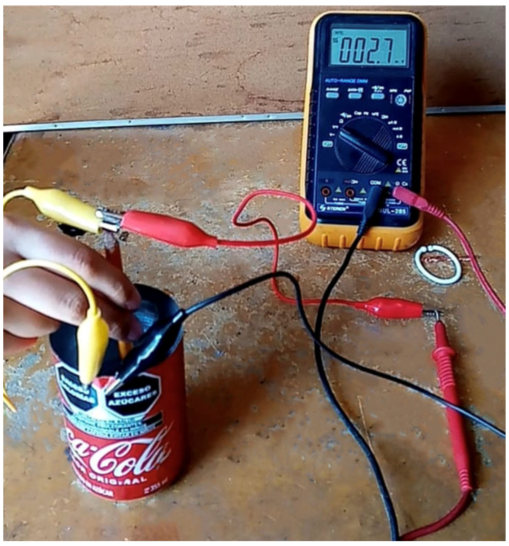

Figure 6. Image of an electrochemical cell built using an aluminum can and saline solution (Image extracted from a students' report).

3.7. Stoichiometry by Precipitation Reactions

Precipitation reactions can be perfectly used to introduce stoichiometric calculations, such as yield percent since the nature of the reaction products allows them to be easily recognized and recovered. Three precipitation reactions were studied. The first one consisted of the precipitation of the casein from milk in an acid medium, which may be achieved with a sample of whole milk and vinegar [55] (Figure 7). Due to the complexity of the corresponding chemical reaction for an introductory chemistry course, this activity was just used as an illustrative example.

Figure 7. Filtration of casein precipitated from a sample of milk (Images extracted from a students' report).

The other two experiments dealt with the precipitation of phosphates in acid medium using magnesium hydroxide (milk of magnesia) from cola soda ($3Mg(OH)_{2\ (aq)} + 2H_3PO_{4\ (aq)} \rightarrow Mg_3(PO_4)_{2\ (s)} + H_2O_{\ (l)}$) and detergent ($Mg(OH)_{2\ (aq)} + NH_4Cl_{\ (aq)} + \frac{1}{2}Na_2HPO_4\ (aq) \rightarrow MgNH_4PO_{4\ (s)} + NaCl_{\ (aq)} + H_2O_{\ (l)}$) [56]. The reactions were easily carried out, and the corresponding solid was recovered by simple filtration (for example, using a common funnel or the top part of a bottle and coffee filter paper or a paper napkin). After letting the samples dry for a few hours exposed to the sunlight, the solid was weighed using a kitchen scale, and the yield percentage was estimated.

3.8. Chemical Kinetics

Some chemical reactions show a sudden change in a property due to an increase or decrease in the concentration of a substance involved. These types of reactions are often compared to a clock alarm since there is no evidence of the reaction until an alert or abrupt change is triggered [57]. Such modification may be appreciated, for example, as a color modification, and, in turn, this may be an indication of the concentration of the reagent at a specific period; hence, their study may provide important information related to the kinetics of the reaction, especially the reaction order.

In this experiment, a redox reaction between a blue food coloring and hydrogen peroxide (H_2O_2) was carried out, and the concentration of the dye was estimated by tracking the R-index of the RGB scale throughout the reaction process [58,59]. First, a teaspoon of baking soda (sodium hydrogencarbonate ($NaHCO_3$)) was mixed with 10 mL of drinking water and, subsequently, 10 mL of H_2O_2 were added. Then, the solution was poured into a clear container and placed on a red background. A smartphone with an RGB analyzer app was set over the reaction container, focusing the camera on a top view of the center of the vessel. Before starting, the initial R-index was recorded as the blank (R_{blank}). Next, 1 or 2 drops of blue food coloring were added and mixed; immediately, the timer was started, and the following R-index values were registered every 15 s. The reaction finished when the blue color had faded, and the mixture had turned red (Figure 8).

The results obtained were analyzed according to Beer-Lambert's Law, $A = \varepsilon c x$ [60], where A is the absorbance of the substance, ε the absorption coefficient, c the molar concentration, and x the path length. Since the concentration of a substance is directly proportional to the absorbance, by estimating this amount, it was possible to qualitatively establish the behavior of the concentration throughout the reaction, and, therefore, determine a reaction order. The calculations performed were as follows: first, the transmittance T of the dye was estimated as the ratio R/R_{blank}; then, the corresponding absorbance was calculated as $A = -logT$; lastly, the following plots were sketched: (a) zero-order: A vs. time, (b) first-order: $ln\ A$ vs. time, and (c) second-order: A^{-1} vs. time. The graph that better adjusted to a linear fit was the one that indicated the reaction order.

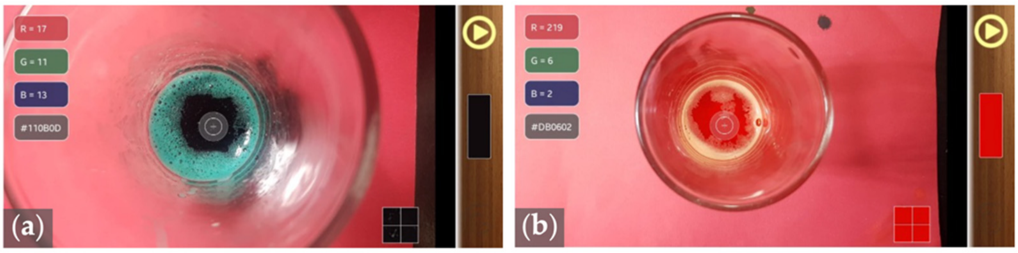

Figure 8. Image of the chemical reaction performed and record of the *R*-index using ColorMeter Free app. (**a**) Addition of blue food dye at the beginning of the reaction. (**b**) View of the system once the reaction was completed.

3.9. Chemical Equilibrium

Natural pH indicators are organic substances that show distinctive colors depending on the acidity or basicity of the medium; for example, red cabbage contains anthocyanin that shows red tones in acid medium, blue-violet in neutral medium, and yellow-green in basic medium, respectively [61]. This is the result of an acid–base reaction between a compound in the medium and the pH indicators acting as weak acids. Therefore, according to Le Châtelier's Principle, a change in the concentration of hydronium ions will result in reversible reactions to restore equilibrium, where the chemical structure of the corresponding conjugate base can be macroscopically identified by a specific shade [62].

A challenge to prepare several natural pH indicators by common extraction procedures was presented and, first, mix them with an acid substance and then, with a basic substance to observe a change in the equilibrium. Moreover, a qualitative colorimetric pH scale was built, where the equilibrium reactions were explained based on Le Châtelier's Principle (Figure 9).

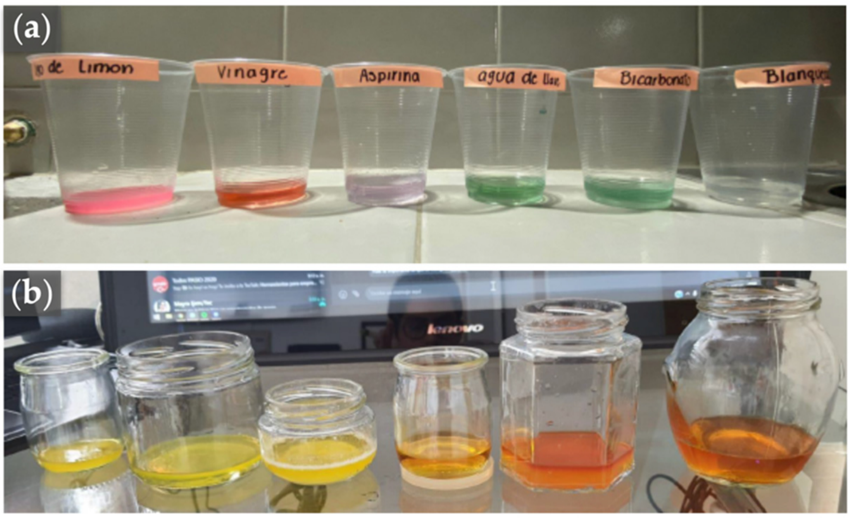

Figure 9. Observed pH colors for different substances (from left to right: lemon juice, vinegar, acetylsalicylic acid, water, baking soda, and bleach) with (**a**) red cabbage and (**b**) turmeric indicators (Images extracted from a students' report).

Additionally, a video in which the equilibrium reaction

$$4Cl^{-}{}_{(aq)} + Co(H_2O)_6{}^{2+}{}_{(aq)} \rightleftharpoons CoCl_4{}^{2-}{}_{(aq)} + 6H_2O_{(l)}$$

takes place was analyzed to explain the equilibrium changes caused by the addition of water, concentrated hydrochloric acid, and sodium chloride and the increase and decrease of temperature.

3.10. Acid–Base Titration

Titration is the classical analytical method used in quantitative determinations of the concentration of a substance. In the food industry, the acid content has an impact on the taste, color, microbial stability, and quality of preservation, among others, of food and may be estimated by an acid–base titration. For instance, the determination of acetic acid content (CH_3COOH) in vinegar samples may be easily performed as an at-home experiment [63] with baking soda solution ($NaHCO_3$), according to the following reaction:

$$CH_3COOH_{\,(aq)} + NaHCO_{3\,(aq)} \rightleftharpoons CH_3COONa_{\,(aq)} + H_2O_{\,(l)} + CO_{2\,(g)}.$$

A ~1 *M* baking soda solution (using kitchen scales and drinking water) and a natural pH indicator (previously tested in the chemical equilibrium experiment Section 3.9) were prepared. With a measuring cup, around 5 mL of vinegar were transferred into a clear vessel, mixed with some drinking water and a few drops of the pH indicator to be able to qualitatively identify the equivalence point by the color change. The baking soda solution was placed in a graduated syringe (which replaced a burette), and the dropwise addition to the vinegar sample began, mixing every drop with a spoon until the color of the system was the one corresponding to the neutral pH (Figure 10). Finally, the molarity (*M*) of the acid was calculated as

$$M_{acid} = (M \times V)_{baking\ soda} / V_{acid},$$

where $V_{baking\ soda}$ stands for the total volume spent of the baking soda solution. The total acidity content was then reported as percent mass (% m/m) and compared with the theoretical content published.

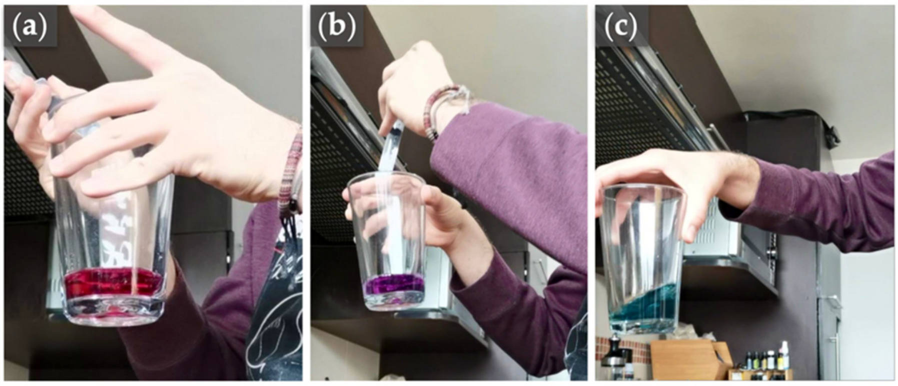

Figure 10. Titration of vinegar with baking soda solution, using red cabbage as the pH indicator. (**a**) Initial view of the reaction system (acid medium). (**b**) Equivalence point of the titration. (**c**) View of the reaction system after the equivalence point (basic medium) (Images extracted from a students' report).

Additionally, an acid–base titration simulator was used [64], wherein different indicators were selected, and a titration curve was generated.

4. Research Design

4.1. Evaluation and Competencies Achievement

The following activities aimed to respond to RQ2, which is related to the learning outcomes after completing this online laboratory course. Students were asked to complete a diagnostic questionnaire at the beginning of the academic period (pre-test) and to take it again once it ended (post-test). It consisted of thirteen questions of several formats (multiple choice, match columns, complete sentences, etc.) and was applied on Canvas (a Learning Management System LMS platform). The rating scale ranged from 0 to 100 points, with 70 being the minimum passing mark accepted by the Tecnologico de Monterrey. The improvement of knowledge was divided into five percentiles of 20% each, which were assigned as the following examples explain. If in the pre-test someone scored 60 points and in the post-test 100 points, this would mean that he/she was able to get the 40 points missing to have a perfect mark; hence, this case will be in percentile I (100%). An alternative example is if another person obtained 35 in the pre-test, to be in the highest percentile, he/she would need 65 points in the post-test; however, if the final grade achieved was 75 points (i.e., only 40 points more), this case will fall in percentile III (60%).

The core topics were equitably distributed in the questionnaires. For Q1021, the topics covered were laboratory reports, safety, material and instruments, volume measuring, basic statistical calculations, mixtures separation, preparation of solution and dilutions, redox reactions, cells potential, electrochemical cells, electrolytes, and colligative properties. The topics addressed in Q1023 were stoichiometry, limiting reagent, chemical equations of double substitution reactions, reaction rate, and basic statistical calculations.

The learning activities were graded according to an evaluation system outlined in Table 4; using the same scale as in the questionnaire described above. These included individual quizzes focused on the key concepts involved in the experiment to be performed (Q_{pre}) and others intended to assess procedural skills and the application of the topics in real contexts (Q_{post} and FE). Moreover, reports (R) from the experimental sessions and a solution of a project based on a real case referred to as problem situation (PS) were submitted in teams. The teacher provided constant feedback to the teams when they were experimenting (ED) and by assessing their reports; also, personal observations were shared considering the results from exams.

Table 4. Evaluation system of the courses Q1021 and Q1023.

Criterium	%
$\boldsymbol{ED}$ = Experimental performance	8
$\boldsymbol{Q_{pre}}$ = Pre-experimental quizzes	5
$\boldsymbol{Q_{post}}$ = Post-experimental quizzes	8
$\boldsymbol{R}$ = Reports	26
$\boldsymbol{FE}$ = Final exam	30
$\boldsymbol{PS}$ = Solution to problem situation	23
$\boldsymbol{FG} =$ Final grade $\left(\boldsymbol{ED} + \boldsymbol{Q_{pre}} + \boldsymbol{Q_{post}} + \boldsymbol{R} + \boldsymbol{FE} + \boldsymbol{PS}\right)$	100

Then, the final grade (FG) obtained was related to a domain level of competencies achievement as follows [31]:

- **Domain level 3** (score: $90 \leq FG \leq 100$) stands for an excellent accomplishment of competencies. The learner outstandingly completed all the activities and demonstrated distinctive knowledge.
- **Domain level 2** (score: $80 \leq FG \leq 89$) was reached when the competencies were satisfactorily gained, and all the grading activities were completed. The acquired knowledge was acceptable, but some concepts needed to be clarified.
- **Domain level 1** (score: $70 \leq FG \leq 79$) refers to the minimum passing execution. Competencies were regularly fulfilled, and activities were partially delivered and needed improvement. The learning outcomes showed confusion in the main topics.
- **Domain level 0** (score: $FG \leq 69$) was assigned when most of the competencies were not achieved, and there were significant deficiencies in the comprehension of the theoretical background.

4.2. Surveys of Perceptions

RQ3, regarding the students' perceptions after completing these courses, was cleared up with initial and final survey instruments (the English translation of the surveys is incorporated as Supplementary Materials S1 for publication purposes). The first survey included five multiple-choice items, three referring to the participants' background with other virtual laboratories; one related to the formats they considered to work better as learning tools (i.e., simulators, lectures, scientific article review); and the last one about the expectations of the class. The second survey had 26 items, 14 of which measured the point of view about experiments with daily-use materials, videos, and simulators; 10 items referred to the sense of competencies' accomplishment; and the last 2 items addressed the satisfaction after taking the courses. All items were assessed with a 5-point Likert scale [65]: Strongly Disagree (SD), Disagree (D), Neutral (N), Agree (A), and Strongly Agree (SA). Finally, there were two open-ended questions to discuss the positive and negative impressions.

Based on the curricular objectives [36,37], five common competencies were intended to be developed during both Q1021 and Q1023: conduct experiments considering the general safety standards in the laboratory (C1), handle correctly the chemicals considering the corresponding risks and precautions (C2), use properly the most common laboratory instruments (C3), express a measurement with the corresponding error (C4), and perform statistical analysis of a set of experimental data (C5).

There were five other competencies specific to each of the courses outlined ahead:

- Q1021. Identify the physicochemical properties of substances and use them to separate the different components of a mixture (C6A), prepare solutions of a defined concentration (C7A), plan a sequence of dilutions from a stock solution (C8A), explain a phenomenon involving oxidation-reduction reactions (C9A), and build a galvanic cell with all its components (C10A).
- Q1023. Calculate the yield of a chemical reaction from its balanced equation (C6B), experimentally demonstrate the order of the chemical reaction related to kinetics (C7B), predict the direction of a chemical reaction as a result of a change in the reaction conditions (C8B), relate chemical equilibrium with a pH scale built using a natural acid–base indicator (C9B), and calculate the unknown concentration of a sample from a reagent of known concentration in acid–base reactions (C10B).

4.3. Data Statistical Analysis

The replies provided were treated using descriptive statistics to determine the frequency and percentage of each survey item. The data collected were examined using IBM SPSS Statistics version 26 and Microsoft Excel v. 16.55. Qualitative data from both open-ended questions were categorized by analyzing the content to have an insight into the perceptions. To sort out the responses, a coding system was applied to logically pool them by their frequency and assign them into an adequate classification labeled with a specific number [66].

For Q1021, the answers received were initially divided considering the chemistry and non-chemistry approach of the degrees (refer to Table 1 for more detail). However, the Student's *t*-test statistical analysis determined there were no significant differences in the perception of these groups.

5. Results and Discussion

The reliability of the results concerning the acceptance of the distance teaching format was assessed using Cronbach's alpha values. According to Cortina [67], a minimum acceptable α coefficient should be between 0.65 and 0.8 (or more) and values less than 0.5 are inadmissible. This test was applied, keeping all the items intact from the answers of both final surveys, Q1021 and Q1023; and the results displayed $\alpha = 0.95$ and $\alpha = 0.94$, respectively, which demonstrated excellent internal consistency of the instruments. The corresponding findings are discussed in the following sections.

5.1. Preferred Class Format

According to the results of the Q1021 initial survey, undergraduates who had already been involved in virtual laboratories accounted for 80% of the respondents, and 49% were not satisfied with the previous experience. From these, 12% worked with real-time experiments conducted by the teacher, 21% used demonstration videos, 54% performed at-home experiments, and 13% practiced with simulators.

Figure 11 shows the results obtained from the question: "*Which format from the online experimental chemistry course do you think can contribute the most to your learning of the topics?*". The answers were ranked in order of preference from 1 to 5, where the number 1 was assigned to the top choice. In Q1021, the first place was real-time demonstrations done by the teacher with 65%; the second option was for videos held in a laboratory with 17%; followed closely by experiments with simple materials available at home with 14%. In Q1023, the item corresponding to real-time demonstrations conducted by the teacher had a much lower percentage (43%), and the experiments carried out with simple materials available at home increased (43%); the next option chosen, with 12%, was videos of experiments in the laboratory; and simulators were the fourth option for both, with 5% for Q1021 and 2% for Q1023.

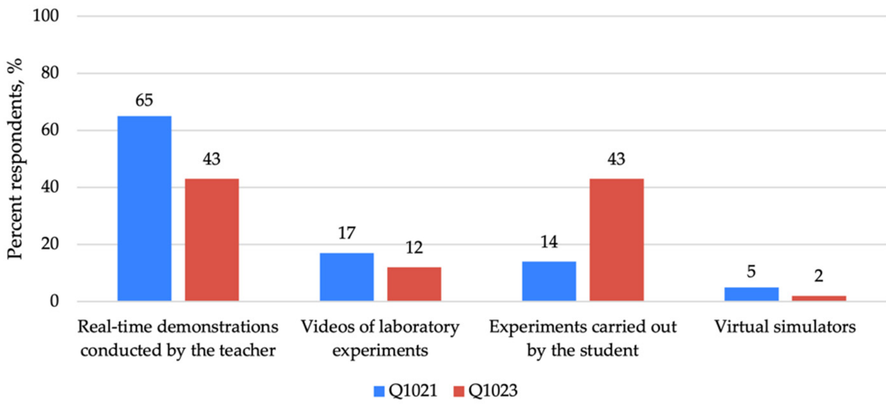

Figure 11. Students' distribution (%) of their preferred teaching formats before taking the courses Q1021 (blue) and Q1023 (red).

A clear difference can be observed in the item "Real-time demonstrations conducted by the teacher" between Q1021 and Q1023. In the first one, it may be assumed that students wanted the instructor to execute the demonstrations due to previous bad experiences in other virtual laboratories. Fortunately, this perception changed in the second course, where the preference leaned towards carrying out experiments with materials available at home.

A central part of the final survey was based on the opinions regarding different attributes of the formats used. Table 5 shows the percentages of students that classified each item using a Likert scale; for analysis purposes, answers were pooled as SA/A for "Strongly agree" and "Agree", N for "Neutral", and SD/D for "Strongly disagree" and "Disagree". Items were assorted as homemade experiments (E1–E11), simulators (S1–S2), and demonstration videos (D1). The highest percentages of SA/A in Q1021 were for items related to the indications with 91% (E9) and the benefit that the at-home experiments provided to understand the concepts (E10), also with 91%. In Q1023, the highest percentages for SA/A were for E2 (finding an adequate space to work), E6 (length of experiments), E9 (instructions), and S2 (simulators as a complement to understand the concepts), all with 95%. Contrastingly, in Q1021, the lowest percentage of SA/A was for the item related to the replacement of laboratory volumetric equipment (E3), ending in 61%; followed by E4 (replacement of non-volumetric material equipment) with 76%; and E11 (at-home experiments allow to apply chemistry in everyday life) with 77%. In contrast, in Q1023, the lower percentage belonged to E3 (64%), followed by E11 (77%). In the SD/D responses, except for E3, which was 18% for Q1021 and 16% for Q1023, the rest of the items were below 10%. It is interesting that in 9 of the 14 items of Q1023 no one selected SD/D.

Table 5. Results of opinions regarding the teaching formats used: experiments carried out at home (E), virtual simulators (S), and demonstration videos (D), for the online courses "Chemical Experimentation and Statistical Thinking I (Q1021) & II (Q1023)"; where the numbers represent the percentage of students that selected that qualification.

Item	Description	Course	SA/A	N	SD/D
Homemade Experiments	E1. The requested material was easy to gather.	I	88	7	5
		II	91	9	0
	E2. By the nature of the experiment, it was easy to find an adequate space at home to perform it.	I	81	13	7
		II	95	2	2
	E3. Household utensils adequately replaced specialized laboratory volumetric equipment.	I	61	21	18
		II	64	20	16
	E4. Household utensils adequately replaced specialized non-volumetric laboratory equipment.	I	76	15	9
		II	84	11	5
	E5. The procedure performed was easy to execute.	I	89	8	3
		II	91	9	0
	E6. The length of the experiments was adequate.	I	88	9	3
		II	95	5	0
	E7. I felt safe while I performed the experiments.	I	89	7	4
		II	91	9	0
	E8. After experimenting, it was easy for me to clean the materials and remove any residues.	I	85	7	7
		II	93	7	0
	E9. The instructions were clear and I felt I received appropriate guidance.	I	91	5	4
		II	95	2	2
	E10. The experiments helped me to understand the concepts of the class.	I	91	5	3
		II	93	7	0
	E11. Unlike laboratory tasks, experiments performed at home allow me to apply the fundamentals of chemistry in everyday life.	I	77	15	7
		II	77	20	2
Simulators	S1. The chosen simulators are intuitive and user-friendly.	I	87	11	3
		II	91	9	0
	S2. The simulators served as a complement to understand the concepts of the class.	I	83	13	4
		II	95	5	0
Demonstration Videos	D1. The demonstration videos served as a complement to understand the concepts of the class.	I	87	10	3
		II	86	14	0

It was expected that the learners would feel it was not easy to substitute both volumetric and non-volumetric materials with ordinary goods; hence, E3 and E4 received the lowest percentage of SA/A and the highest of SD/D.

The positive percentages for E11 were also relatively low when compared with the other attributes of the teaching formats. It stated that at-home experiments allow the implementation of chemistry in everyday life, and the results indicate that less than a quarter considered activities in an actual laboratory could be more valuable.

In Q1023, participants affirmed it was easy to find an adequate space at home to work; also, they expressed that the length of the experiment was appropriate. This remarkably supports the relevance of designing an adequate sequence of experiments and that the selection was suitable to be performed remotely. The impact of the resources used as facilitators and means of reinforcement to understand the concepts was also underlined; in this context, the use of simulators proved to be an excellent complement for the learning process [17,19].

Finally, the importance of giving clear and precise instructions is highlighted and is consistent with other publications regarding the relevance of the teacher's role [6,11,68].

5.2. Perception of Knowledge and Skills Achievement

The survey explored self-perception about the competencies achieved after attending the online laboratories. Figure 12 shows the impressions on the five common competencies. In Q1021, the percentage of members who agreed (SA/A) on having achieved these competencies is between 79% and 91%, where C2 got the lowest percentage and C1 the highest. In the case of Q1023, the interval is between 84% and 93%, with the smaller percentage being for C3 and the biggest for C4. In both courses, the group who considered they did not achieve the competencies was between 0% and 6%, and the neutral answers ranged between 6% and 15%. Competency C2 presented the highest percentage of SD/D in terms of the achievement of the competency (6% in Q1021 and 5% in Q1023).

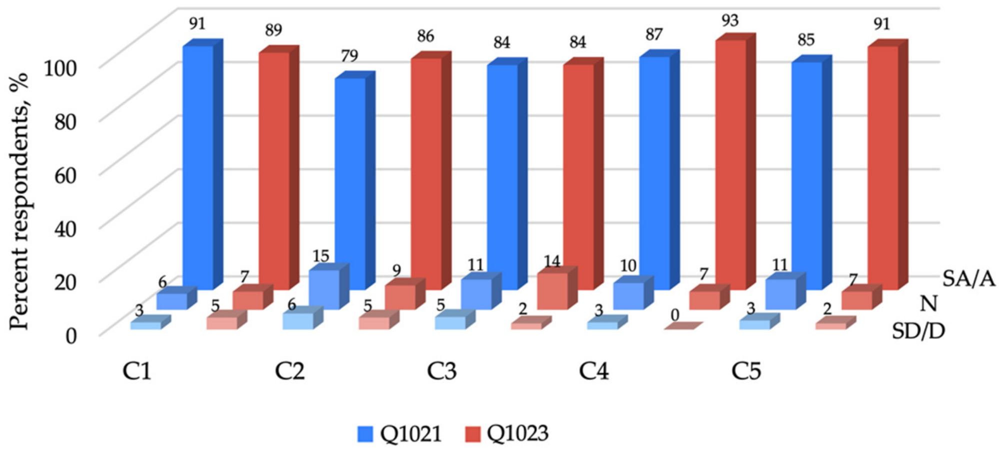

Figure 12. Students' distribution (%) of their perception about common competencies achievement in both courses Q1021 (blue) and Q1023 (red) (C1: conduct experiments considering the general safety standards in the laboratory, C2: handle correctly the chemicals considering the corresponding risks and precautions, C3: use properly the most common laboratory instruments, C4: express a measurement with the corresponding error, C5: perform statistical analysis of a set of experimental data, SA/A: strongly agree/agree, N: neutral, SD/D: strongly disagree/disagree).

Attendants of Q1021 believed they learned about safety measures for experimental work (C1). This could have been favored by having encouraged them throughout the activities to use safety and protection equipment, such as goggles, lab coats (or aprons in its absence), kitchen gloves, and shoes with closed-toes and heels. Competency C2, which refers to the handling of chemical substances, had the lowest percentage in Q1021, possibly because no chemical reagents requiring special handling were used; although an increase in the percentage was observed in Q1023, the score is still low in comparison to other competencies. In Q1023, C3 was the competency with the lowest numbers, which may be explained since common laboratory glassware (such as pipettes, burettes, volumetric flasks) were not available and were replaced by commonly used instruments.

The greatest percentages of acceptance for competencies C4 and C5 were obtained in Q1023, reporting a significant increase in comparison with Q1021. This is probably because in Q1021 the topics related to the expression of the error in measurements and statistical analysis of data were addressed for the first time, but they were reinforced in the second period (consult Table 2 for the complete list of topics).

Figure 13 shows the perception of the procedural competencies specific for Q1021. The highest percentage of SA/A responses is found in C9A (94%), followed by C8A (92%), C6A (90%), and C7A (88%); whereas the lowest value was obtained in C10A (81%). Neutral responses ranged from 5% to 13% of respondents, while those who felt that they did not develop these competencies (SD/D) ranged from 1% to 6%.

Given the large percentage of acceptance in C4, it may be assumed that the redox experiment (Section 3.5) was adequate. The lowest values in C10A may be justified since it was not easy to build a homemade galvanic cell due to the lack of materials, and this topic was mainly reviewed with videos and simulators. This observation reinforces the initial idea that at-home experiments help them to achieve procedural skills.

Figure 13 shows the point of view about the development of specific Q1023 competencies. In general, the SA/A of students' replies for each competency were very similar, with values between 91% and 95%, being the lowest for C10B and the highest for C8B. Between 5% and 9% opted for a neutral answer, and no one chose SD/D.

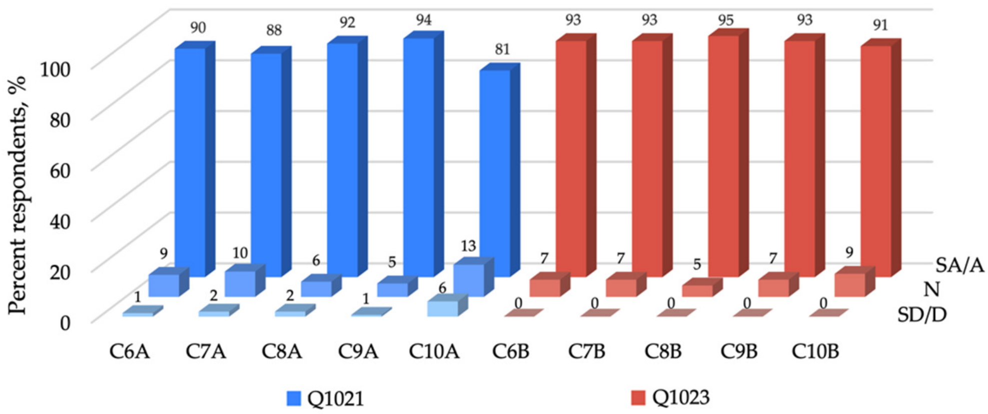

Figure 13. Students' distribution (%) of their perception about specific competencies achievement in the courses Q1021 (blue-A) and Q1023 (red-B) (C6A: identify the physicochemical properties of substances and use them to separate the different components of a mixture, C7A: prepare solutions of a defined concentration, C8A: plan a sequence of dilutions from a stock solution, C9A: explain a phenomenon involving oxidation–reduction reactions, C10A: build a galvanic cell with all its components, C6B: calculate the yield of a chemical reaction from its balanced equation, C7B: experimentally demonstrate the order of the chemical reaction related to kinetics, C8B: predict the direction of a chemical reaction as a result of a change in the reaction conditions, C9B: relate chemical equilibrium with a pH scale built using a natural acid–base indicator, C10B: calculate the unknown concentration of a sample from a reagent of known concentration in acid–base reactions, SA/A: strongly agree/agree, N: neutral, SD/D: strongly disagree/disagree).

Broadly speaking, there is an increase in the percentage of favorable responses obtained in comparison with the results from Q1021. One possible reason is that the design, in terms of distribution and extension of each activity, of the sessions in Q1023 was improved. In addition, the thematic content of the second course favored proposing more attractive experiments with a greater intellectual challenge.

5.3. *Evaluation of Competencies Achievement*

The learning outcomes provided good insight into the knowledge and competencies domain level acquired as a result of completing these courses. The analysis had two different approaches, estimating an improvement based on the grades of diagnostic tests and assigning a domain level of competencies' achievement.

In Q1021, the average grade on the initial questionnaire was 58 points, and the final was 73 points. By comparing the scores obtained in both tests, a general increase of 15% in the final marks within the ranges of 100 to 90 points and from 89 to 80 points was reported, an increase of 22% was found from 79 to 70 points, and the number of failing scores reduced to 33%. In Q1023, the initial average score was 42 points, and the final was 73 points; wherein 98% of the students started with failing scores and, after taking the lessons, this group reduced to 39%; the scores of the rest were distributed 27% in the range between 100 and 90 points, 34% between 89 and 80 points and also 34% from 79 to 70 points.

Figure 14 shows a chart with the scores' distribution in percentiles where each one represents a range of improvement: (I) 100–80%, (II) 80–60%, (III) 60–40%, (IV) 40–20%, and (V) <20%. In Q1021, 32% of the students showed a recovery of 20% or less in their scores, and only 12% upgraded their marks to the top percentile. In contrast, for Q1023, 30% fell into percentile (I), and only 13% exhibited progress of 20% or less.

Overall, the grades' increase was more noticeable in Q1023. This may be because it was a second online chemistry laboratory; consequently, students were already familiar with this teaching format and might feel encouraged to keep a positive attitude.

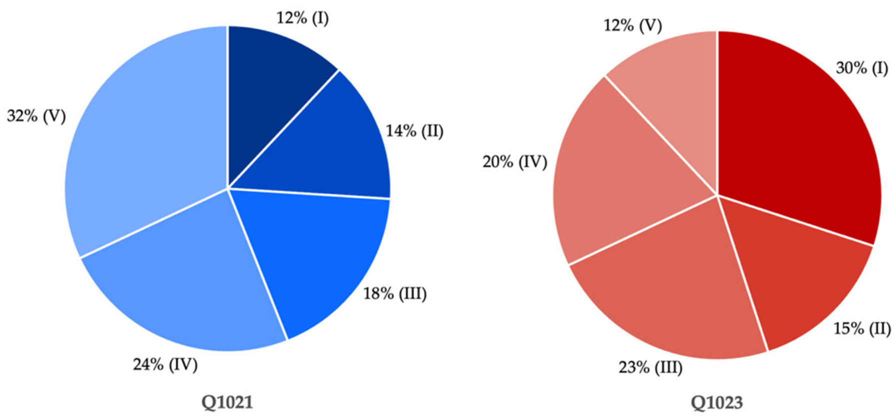

Figure 14. Students' distribution (%) in the ranges of scores' improvement (I: 100–80%, II: 80–60%, III: 60–40%, IV: 40–20%, and V: <20%) as a result of completing the courses Q1021 (blue) and Q1023 (red).

Moreover, the grade obtained was associated with a domain level of competency achievement. Figure 15 contains a scheme that illustrates these results, where both courses showed a similar distribution. That is, 68% of the students reached the maximum domain level (DL 3); 26% from Q1021 and 23% from Q1023 fell in the domain level 2 (DL 2); and 5% and 9% from Q1021 and Q1023, respectively, were in domain level 1 (DL 1). While in Q1023, everyone gained some competency domain level, in Q1021, only 1% failed to reach a certified level (DL 0).

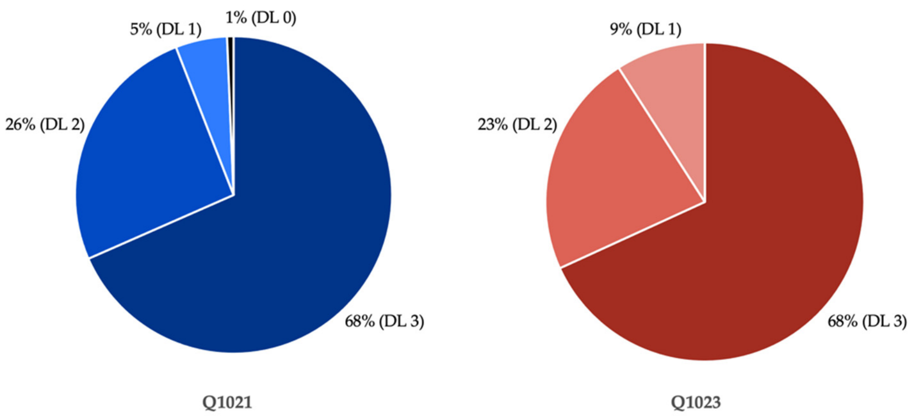

Figure 15. Students' distribution (%) of final grades (FG) in the domain levels (DL) of competencies achieved (DL 3: $90 \leq FG \leq 100$, DL 2: $80 \leq FG \leq 89$, DL 1: $70 \leq FG \leq 79$, DL 0: $FG \leq 69$) as a result of completing the courses Q1021 (blue) and Q1023 (red).

The expertise of the three institutional competencies stated in Section 2.3. was corroborated through the course evaluation instruments (Table 4), and, in turn, the learners stated their standpoint about their acquisition of skills C1–C10 (Figures 12 and 13). The results of the reports and quizzes were associated with the first competency (IC1) centered on being able to explain and demonstrate the behavior of observed phenomena through the application of the concepts learned (pertinent to C1, C2, C6A, C9A, C8B, and C9B). The experimental performance, the final exam, and the solution to the problem situation addressed the second (IC2), focusing on problem-solving, which includes a deep analysis of the case, taking decisions, and implementing actions that meet with the suitable standards (connected with C1, C2, C4, C5, C6B, C8B, and C10B). The experimental performance was further used to assess the third competency (IC3), which was mainly focused on the laboratory activities and statistical results management (linked to C1, C2, C3, C4, C5, C7A, C8A, C10A, and C7B).

The continuous evaluation promoted the mastery of the competencies. For instance, after each report was submitted by the students, the teacher provided formative feedback, which was ultimately reflected in an improvement in their grades and a better development of the procedural (IC3) and intellectual skills (IC1 and IC2). Specifically, by the end of the period, a better organization within the teams and a more accurate execution of the experiments were observed; likewise, an enhancement of critical thinking was appreciated in the discussions of the reports, the argumentation of the exams, and the elucidation of the problem situation.

The overall results were analyzed based on the learners' scores. From both courses, the average range of improvement fell in percentile III; i.e., Q1021 showed an upgrade of 41% (58 to 73 points) and Q1023 an advance of 55% (42 to 73 points). Since these marks were based on the diagnostic questionnaires that included the most important topics (safety, use of laboratory materials, basic operations, electrochemistry, stoichiometric calculations, kinetics, chemical equilibrium, acid–base titration, and statistical data analysis), this means that most of the students were able to achieve IC1 and IC2. The final average of both classes was 92 points; this mark is contemplated in DL 3, which stands for an excellent accomplishment of all institutional competencies.

The general impression of the students was that the laboratory could not be entirely substituted; this is supported by a low percentage of achievement of competencies C2, C3, and C10A. However, they not only believed they had gained the corresponding competencies (Figures 12 and 13), but the numbers prove the vast majority indeed reached an acceptable domain level (Figures 14 and 15). This is consistent with the idea of significant learning because the grades showed it was possible to assimilate concepts through at-home experiments supported with virtual tools (simulators and videos) [19,22,25,69].

5.4. Online Laboratory Course Experience

This section addresses a discussion regarding the sense of accomplishment after finishing the programs. This analysis involves two open-ended questions, and two items ranked with a Likert scale.

The feedback of the open-ended question "What were the two best aspects of your experience in this online laboratory course?", for both classes, showed responses confirming the participants were satisfied when they performed the experiments adapted for the remote sessions (27%) and when they used simple and accessible materials (15%). Other replies indicated that the activities helped them, whether to integrate knowledge (11%) or to achieve effective learning (15%); also, there were declarations referring to the relevance of the teacher's help and advice (11%). Additionally, a few students (7%) mentioned that the lessons were amusing and dynamic. Finally, a lower percentage (4%) considered that the class was challenging and motivating and that they rather use simulators and videos (3%). The remaining responses were random ideas that could not be categorized (7%). Figure 16 shows a word cloud with the most frequent responses.

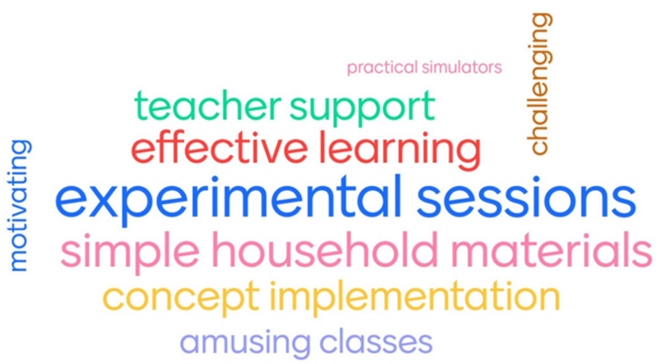

Figure 16. Word cloud of the best aspects of the students' experience with the courses Q1021 and Q1023.

The students enjoyed experimenting because of the intellectual challenge, and they found the activities to be an adequate complement to the theoretical content. The fact that the materials were readily available also received good rates and, naturally, the role of the teacher was a medullar topic [11,19,20]. These results are comparable with the percentages shown in Table 5, where items E9 (clear instructions and appropriate guidance) and E10 (experimental activities contributed to understanding the concepts) had notably high percentages of SA/A scores. Likewise, this is supported by other studies published, where authors highlight the relevance of homemade experiments in learning achievement [13,14,21,22]. A small percentage of students mentioned the use of simulators as the best aspect (S2); specifically, in Q1023, the item related to this matter had the leading percentage (along with items E2, E6, and E9).

Concerning the second open-ended question of the survey "Could you mention two areas of opportunity (for improvement) that you have identified in this online laboratory course?", for both programs, 16% requested more accessible materials. Another 16% asked to improve the content in terms of workload; that is, to summarize the theoretical information before carrying out the experiments, in addition, to reducing the amount of homework, and other percentages (8%) mooted to minimize the content of the reports. Moreover, 13% pointed out it would be better to assign more time to each experiment. Further, there were criticisms related to the tutoring and demanded clearer instructions in each activity (12%), along with better guidance during the performance. The lowest percentages suggested limiting the use of simulators (5%) and enhancing teamwork dynamics (3%). Furthermore, 4% wrote responses related to improving their learning in a personal way and 15% just included general positive remarks. From all the commentaries, 8% were random and could not be categorized. The most frequent responses to this question are schematized in a word cloud presented in Figure 17.

Figure 17. Word cloud of the areas of opportunity according to students' experience with the courses Q1021 and Q1023.

In the first question, some students reported they were satisfied with at-home experiments using phrases such as *"the experiments were easily developed"* and *"the best experiences were the experiments done at home"*; the other group requested to review and better organize the classes and the necessary materials. Moreover, some of the phrases used were: *"the syllabus content is too long"*, *"ask for materials easier to get"*, and *"enhance the length of the sessions"* as improvement aspects. Accordingly, in Table 5, item E6 (related to the length of the experiments) was better ranked in Q1023 than in Q1021. Therefore, it is consistent with the recurrent recommendation about increasing the time designated to finish the trials.

An issue that resulted in divided opinions referred to the assistance. Examples of positive answers include: *"excellent teacher and guidance"* and *"I liked the explanation before the experiments"*; but some declared *"the teacher should provide more support"* and *"more detailed explanations"*. Despite several comments describing areas of opportunity, there were more opinions expressing approval of the design, the experiments, and the teachers' role.

The results of the surveys concerning the students' expectations about the contribution of the online laboratory to their learning process and their feeling of accomplishment at the end are compared in Figure 18. The percentages of SA/A in Q1021 were 77% before and 92% after the course, respectively, which represents a 15% increment of fulfillment. In Q1023, initial and final percentages of SA/A were similar (93% and 91%, respectively); however, there was a slight decrease in the number of pleased participants. The percentage of neutral opinions in Q1021 decreased from 18% to 5%; unlike in Q1023, where an increment from 5% to 9% was appreciated. In Q1021, only 5% presumed this class would not contribute to their learning (SD/D), but this value decreased even more after the lessons (to 2%). In Q1023, this criterion decreased from 2% in the initial survey to 0% in the final inquire. The positive reception at the end surpassed the expectation, and the learners who initially felt they would not be part of a valuable experience changed their perspectives.

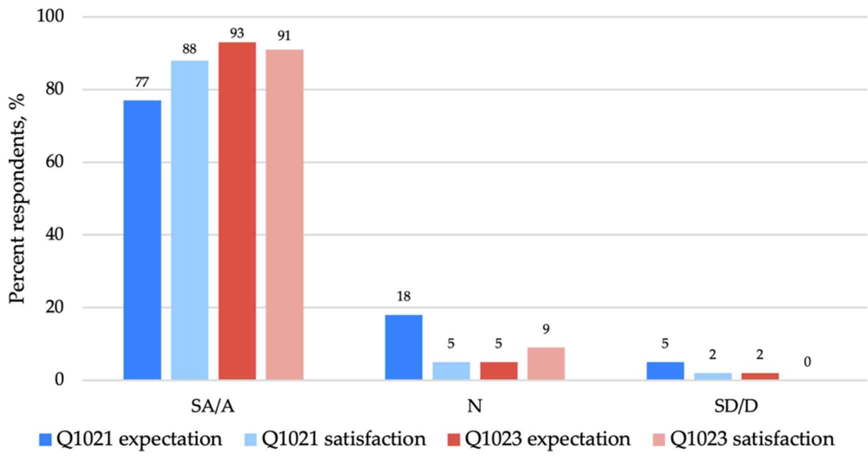

Figure 18. Students' distribution (%) of their perception before (expectation) and after (satisfaction) the courses Q1021 (blue) and Q1023 (red) (SA/A: strongly agree/agree, N: neutral, SD/D: strongly disagree/disagree).

One decisive parameter of the effectiveness of this adaptation was whether the students would recommend this online mode or not. In Q1021, 88% selected SA/A, 7% N, and 5% SD/D; and in Q1023 81% chose SA/A, 14% N, and 5% SD/D. Although around 5% would not recommend this remote laboratory, a much higher percentage (i.e., about 85%) of the participants from both courses would strongly recommend this class format (with at-home experiments, videos, and simulators).

6. Conclusions and General Recommendations

This paper presents a brief description of simple experiments that cover the topics of an introductory chemistry course at an undergraduate level. The idea arose from a worldwide necessity where the COVID-19 pandemic demanded distance teaching. The proposed activities can be carried out safely at home since they are planned to be conducted with materials and substances of daily use; nonetheless, the supervision of an expert is imperative.

Regarding the first question proposed in this work: RQ1. "*How to adapt a competency-based chemistry laboratory course to an online mode?*", a homemade chemistry laboratory was effectively remodeled with ten experiments. The implementation triggered the development of the institutional competencies and this was reflected in the results of the evaluation system.

The second research question, RQ2. "*How is the students' learning favored after completing an online laboratory course?*", was discussed according to the academic performance. There was a general increase in the scores of the diagnostic tests, detecting more than 60% of improvement in a quarter of the learners in the first period and half of the students in the second. In conjunction, about 70% of the applicants reached the highest domain level of competencies. These outcomes confirm a successful learning process.

In the last question, RQ3. *"What are students' perceptions after performing chemistry laboratory experiments with daily-use materials and substances?"*, the students believed their development of competencies was adequate. They felt more confident with competencies related to safety measures, explanation of redox reactions, expression of measurements, statistical data management, and prediction of chemical equilibrium shifts. The aspects more appreciated were: at-home experiments carried out with materials easy to gather, direct application of the topics, and the guidance provided by the teacher. On the other hand, optimal management of the content and workload were suggested as possible amendments. The general feeling after completing the courses was that these activities contributed to their training.

Altogether, this research showed that students can accomplish the learning goals and that although some participants had reservations about the format and were reluctant to be involved in this mode, after finishing the tasks, a feeling of general satisfaction predominated. Moreover, most of the class members declared they will indeed recommend this approach. Despite the great efforts, there will always be limitations related to the lack of actual laboratory facilities; for example, the skills to handle real laboratory glassware and specialized equipment may not be attained. The competencies supported in these courses were evaluated within the online conditions; however, the real acquisition of these skills might only be corroborated when students have access to an actual laboratory experience.

The instructor's role was revealed to be a key factor. This involves preparing and organizing the program, giving clear lectures, supervision, and the general assistance provided, such as being available out of hours to work out doubts or to offer supplementary explanations. In addition, the leadership shown promoted a friendly and motivating environment, not only from the perspective of the members' interaction, but also it made the student more willing to learn, to gather the materials, and to get involved in the lessons; collectively, this aroused their scientific awareness. The most important value transmitted by the teacher was to keep a positive attitude and an open mind since skills and knowledge can eventually be gained.

This study shows that even though there may be restrictions in a remote laboratory, there are also many alternatives that could be implemented without compromising the educational quality. It also opened an opportunity to research for new best practices for the following times that may further be applied in other contexts, such as hybrid formats, international groups, lectures where the presence is not mandatory, hands-on workshops, in low-income areas, or at-home review exercises. This work intends to encourage students and teachers to get involved in new activities with the available resources to achieve an enriched understanding and enjoy the experience.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su14052539/s1. Questionnaire.

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References

1. Ali, W. Online and remote learning in higher education institutes: A necessity in light of COVID-19 pandemic. *High. Educ. Stud.* **2020**, *10*, 16–25. [CrossRef]
2. Hodges, C.B.; Moore, S.; Lockee, B.B.; Trust, T.; Bond, M.A. The Difference between Emergency Remote Teaching and Online Learning. Available online: https://er.educause.edu/articles/2020/3/the-difference-between-emergency-remote-teaching-and-online-learning (accessed on 2 December 2021).
3. Serhan, D. Transitioning from face-to-face to remote learning: Students' attitudes and perceptions of using Zoom during COVID-19 pandemic. *Int. J. Technol. Educ. Sci.* **2020**, *4*, 335–342. [CrossRef]
4. Adedoyin, O.B.; Soykan, E. COVID-19 pandemic and online learning: The challenges and opportunities. *Interact. Learn. Environ.* 2020; ahead-of-print. [CrossRef]
5. Ferrer, J.; Ringer, A.; Saville, K.; Parris, M.A.; Kashi, K. Students' motivation and engagement in higher education: The importance of attitude to online learning. *High. Educ.* **2020**, *83*, 317–338. [CrossRef]
6. Simon, L.E.; Genova, L.E.; Kloepper, M.L.; Kloepper, K.D. Learning Postdisruption: Lessons from Students in a Fully Online Nonmajors Laboratory Course. *J. Chem. Educ.* **2020**, *97*, 2430–2438. [CrossRef]
7. Golombek, D. *Aprender y Enseñar Ciencias: Del Laboratorio al Aula y Viceversa*; Santillana: Buenos Aires, Argentina, 2008.
8. Fanguy, M.; Lee, S.Y.; Churchill, D.G. Adapting educational experiences for the chemists of tomorrow. *Nat. Rev. Chem.* **2021**, *5*, 141–142. [CrossRef]
9. D'Angelo, J.G. Choose Your Own "Labventure": A Click-Through Story Approach to Online Laboratories during a Global Pandemic. *J. Chem. Educ.* **2020**, *97*, 3064–3069. [CrossRef]
10. Chandrasekaran, A.R. Transitioning undergraduate research from wet lab to the virtual in the wake of a pandemic. *Biochem. Mol. Biol. Educ.* **2020**, *48*, 436–438. [CrossRef] [PubMed]
11. Sangeeta; Tandon, U. Factors influencing adoption of online teaching by school teachers: A study during COVID-19 pandemic. *J. Public Aff.* **2021**, *21*, e2503. [CrossRef]
12. Galloway, K.R.; Malakpa, Z.; Bretz, S.L. Investigating Affective Experiences in the Undergraduate Chemistry Laboratory: Students' Perceptions of Control and Responsibility. *J. Chem. Educ.* **2016**, *93*, 227–238. [CrossRef]
13. Bretz, S.L. Evidence for the importance of laboratory courses. *J. Chem. Educ.* **2019**, *96*, 193–195. [CrossRef]
14. Bretz, S.L. Novak's Theory of Education: Human Constructivism and Meaningful Learning. *J. Chem. Educ.* **2001**, *78*, 1107. [CrossRef]
15. Bretz, S.L.; Fay, M.; Bruck, L.B.; Towns, M.H. What faculty interviews reveal about meaningful learning in the undergraduate chemistry laboratory. *J. Chem. Educ.* **2013**, *90*, 281–288. [CrossRef]
16. Sunasee, R. Challenges of Teaching Organic Chemistry during COVID-19 Pandemic at a Primarily Undergraduate Institution. *J. Chem. Educ.* **2020**, *97*, 3176–3181. [CrossRef]
17. Villanueva, O.; Zimmermann, K. Transitioning an Upper-Level, Integrated Laboratory Course to Remote and Online Instruction During the COVID-19 Pandemic. *J. Chem. Educ.* **2020**, *97*, 3114–3120. [CrossRef]
18. Jones, E.V.; Shepler, C.G.; Evans, M.J. Synchronous Online-Delivery: A Novel Approach to Online Lab Instruction. *J. Chem. Educ.* **2021**, *98*, 850–857. [CrossRef]
19. Gamage, K.A.A.; Wijesuriya, D.I.; Ekanayake, S.Y.; Rennie, A.E.W.; Lambert, C.G.; Gunawardhana, N. Online Delivery of Teaching and Laboratory Practices: Continuity of University Programmes during COVID-19 Pandemic. *Educ. Sci.* **2020**, *10*, 291. [CrossRef]
20. Scruggs, A.W.; Leamy, K.A.; Cravens, S.L.; Siegel, S.J. Adapting a Biochemistry Lab Course for Distance-Learning during the COVID-19 Pandemic. *J. Chem. Educ.* **2020**, *97*, 2981–2986. [CrossRef]
21. Kelley, E.W. Reflections on three different high school chemistry Lab Formats during COVID-19 Remote learning. *J. Chem. Educ.* **2020**, *97*, 2606–2616. [CrossRef]
22. Selco, J.I. Using Hands-On Chemistry Experiments While Teaching Online. *J. Chem. Educ.* **2020**, *97*, 2617–2623. [CrossRef]
23. Darby, F.; Lang, J.M. *Small Teaching Online: Applying Learning Science in Online Classes*; John Wiley & Sons: San Francisco, CA, USA, 2019.
24. Al-Soufi, W.; Carrazana-Garcia, J.; Novo, M. When the Kitchen Turns into a Physical Chemistry Lab. *J. Chem. Educ.* **2020**, *97*, 3090–3096. [CrossRef]
25. Radzikowski, J.L.; Delmas, L.C.; Spivey, A.C.; Youssef, J.; Kneebone, R. The Chemical Kitchen: Toward Remote Delivery of an Interdisciplinary Practical Course. *J. Chem. Educ.* **2021**, *98*, 710–713. [CrossRef]
26. Bruce, M.R.M.; Bruce, A.E.; Bernard, S.E.; Bergeron, A.N.; Ahmad, A.A.L.; Bruce, T.A.; Perera, D.C.; Pokhrel, S.; Saleh, S.; Tyrina, A.; et al. Designing a Remote, Synchronous, Hands-On General Chemistry Lab Course. *J. Chem. Educ.* **2021**, *98*, 3131–3142. [CrossRef]
27. Schultz, M.; Callahan, D.L.; Miltiadous, A. Development and Use of Kitchen Chemistry Home Practical Activities during Unanticipated Campus Closures. *J. Chem. Educ.* **2020**, *97*, 2678–2684. [CrossRef]
28. Mínguez-Aroca, F.; Moll-López, S.; Llobregat-Gómez, N.; Sánchez-Ruiz, L.M. A Cuboid Registers Topic, Activity and Competency Data to Exude Feedforward and Continuous Assessment of Competencies. *Mathematics* **2022**, *10*, 415. [CrossRef]
29. Nguyen, J.G.; Keuseman, K.J. Chemistry in the Kitchen Laboratories at Home. *J. Chem. Educ.* **2020**, *97*, 3042–3047. [CrossRef]

30. Andrews, J.L.; de Los Rios, J.P.; Rayaluru, M.; Lee, S.; Mai, L.; Schusser, A.; Mak, C.H. Experimenting with At-Home General Chemistry Laboratories During the COVID-19 Pandemic. *J. Chem. Educ.* **2020**, *97*, 1887–1894. [CrossRef]
31. Dieck-Assad, G.; Ávila-Ortega, A.; González Peña, O.I. Comparing Competency Assessment in Electronics Engineering Education with and without Industry Training Partner by Challenge-Based Learning Oriented to Sustainable Development Goals. *Sustainability* **2021**, *13*, 10721. [CrossRef]
32. Ramsden, P. A performance indicator of teaching quality in higher education: The Course Experience Questionnaire. *Stud. High. Educ.* **1991**, *16*, 129–150. [CrossRef]
33. Nogueira, T.; Magano, J.; Fontão, E.; Sousa, M.; Leite, Â. Engineering Students' Industrial Internship Experience Perception and Satisfaction: Work Experience Scale Validation. *Educ. Sci.* **2021**, *11*, 671. [CrossRef]
34. Curtis, D.D.; Keeves, J.P. The Course Experience Questionnaire as an Institutional Performance Indicator. *Int. Educ. J.* **2000**, *1*, 73–82.
35. Otzen, T.; Manterola, C. Técnicas de Muestreo sobre una Población a Estudio. *Int. J. Morphol.* **2017**, *35*, 227–232. [CrossRef]
36. Tecnologico de Monterrey. Q1021. Experimentación Química y Pensamiento Estadístico Fundamental. Available online: https://samp.itesm.mx/Materias/VistaPreliminarMateria?clave=Q1021&lang=ES# (accessed on 15 January 2021).
37. Tecnologico de Monterrey. Q1023. Experimentación Química y Pensamiento Estadístico Intermedio. Available online: https://samp.itesm.mx/Materias/VistaPreliminarMateria?clave=Q1023&lang=ES (accessed on 15 January 2021).
38. Instituto Tecnológico y de Estudios Superiores de Monterrey. *Modelo Educativo Tec21*; Vicerrectoría de Profesional: Monterrey, Mexico, 2018.
39. González-Peña, O.I.; Morán-Soto, G.; Rodríguez-Masegosa, R.; Rodríguez-Lara, B.M. Effects of a Thermal Inversion Experiment on STEM Students Learning and Application of Damped Harmonic Motion. *Sustainability* **2021**, *13*, 919. [CrossRef]
40. Chans, G.M.; Portuguez Castro, M. Gamification as a Strategy to Increase Motivation and Engagement in Higher Education Chemistry Students. *Computers* **2021**, *10*, 132. [CrossRef]
41. López, H.A.; Ponce, P.; Molina, A.; Ramírez-Montoya, M.S.; Lopez-Caudana, E. Design Framework Based on TEC21 Educational Model and Education 4.0 Implemented in a Capstone Project: A Case Study of an Electric Vehicle Suspension System. *Sustainability* **2021**, *13*, 5768. [CrossRef]
42. Membrillo-Hernández, J.; Ramírez-Cadena, M.d.J.; Caballero-Valdés, C.; Ganem-Corvera, R.; Bustamante-Bello, R.; Benjamín-Ordóñez, J.A.; Elizalde-Siller, H. Challenge Based Learning: The Case of Sustainable Development Engineering at the Tecnologico de Monterrey, Mexico City Campus. In Proceedings of the Teaching and Learning in a Digital World, Proceeding of the ICL 2017 Advances in Intelligent Systems and Computing, Budapest, Hungary, 27–29 September 2017; Auer, M., Guralnick, D., Simonics, I., Eds.; Springer: Cham, Switzerland, 2018; Volume 715.
43. Portuguez Castro, M.; Gómez Zermeño, M.G. Challenge Based Learning: Innovative Pedagogy for Sustainability through e-Learning in Higher Education. *Sustainability* **2020**, *12*, 4063. [CrossRef]
44. Secretaría de Gobernación. Norma Oficial Mexicana NOM-018-STPS-2015. Sistema Armonizado para la Identificación y Comunicación de Peligros y Riesgos por Sustancias Químicas Peligrosas en los Centros de Trabajo. Available online: https://www.dof.gob.mx/nota_detalle.php?codigo=5411121&fecha=09/10/2015 (accessed on 9 February 2021).
45. Hernández-Díaz, J.A.; Tecnologico de Monterrey, School of Engineering and Sciences, Mexico City, Mexico. Personal communication, 2018.
46. Ciencias UTP. Laboratorio N°1: Introducción a los Materiales y Mediciones—Parte 1. Available online: https://www.youtube.com/watch?v=KbuSX-iglXA (accessed on 16 February 2021).
47. Gobierno de Canarias. Material de Laboratorio. Available online: http://www3.gobiernodecanarias.org/medusa/contenidosdigitales/ucticee/s2/CD120000011/#/lang/es/pag/b2fec68de2689236004b62d4ef5ca948 (accessed on 16 February 2021).
48. American Association of Chemistry Teachers (AACT). Classroom Resources: Measuring Volume. Available online: https://teachchemistry.org/classroom-resources/measuring-volume-simulation (accessed on 16 February 2021).
49. Islas-Rodríguez, J.M.; Tecnologico de Monterrey, School of Engineering and Sciences, Mexico City, Mexico. Personal communication, 2020.
50. American Association of Chemistry Teachers (AACT). Classroom Resources: Preparing Solutions. Available online: https://teachchemistry.org/classroom-resources/preparing-solutions-simulation (accessed on 23 February 2021).
51. Secretaría de Educación Pública. Experimento 12. Oxidantes y Reductores Caseros. Available online: http://www.cursosinea.conevyt.org.mx/cursos/cnaturales_v2/interface/main/recursos/experimentos/cnexp_12.htm (accessed on 2 March 2021).
52. Mayorga Martínez, L. Sección Experimental-Celdas Galvánicas. Available online: https://www.youtube.com/watch?v=1T0s7uPFGiE (accessed on 2 March 2021).
53. Bertrand, G.L. Electrochemical Cells. Available online: http://web.mst.edu/~{}gbert/Electro/Electrochem.html (accessed on 2 March 2021).
54. Sangri, P.M. Lavanguardia. Experimentos Caseros. Available online: https://www.lavanguardia.com/estilos-de-vida/20141226/54421996635/experimentos-caseros.html (accessed on 2 March 2021).
55. McMaster University. Experiment 11. Proteins and Carbohydrates. Isolation of Casein and Lactose from Milk. Available online: https://www.chemistry.mcmaster.ca/~{}chem2o6/labmanual/expt11/2o6exp11.html (accessed on 11 May 2021).
56. Steve Spangler Science. Invisible Soda. Available online: https://www.stevespanglerscience.com/lab/experiments/invisible-soda/ (accessed on 11 May 2021).

57. Cortés, F. La química y el tiempo. Reacciones reloj. *Educ. Quimica* **1994**, *5*, 74. [CrossRef]
58. Kuntzleman, T. Chemical Kinetics with a Smartphone. Available online: https://www.chemedx.org/blog/chemical-kinetics-smartphone (accessed on 18 May 2021).
59. Nalliah, R.E. Reaction of FD&C Blue 1 with Sodium Percarbonate: Multiple Kinetics Methods Using an Inexpensive Light Meter. *J. Chem. Educ.* **2019**, *96*, 1453–1457. [CrossRef]
60. Harris, D.C. *Análisis Químico Cuantitativo*; Reverté: Barcelona, Spain, 2016; p. 415.
61. Vankar, P.S.; Bajpai, D. Rose anthocyanins as acid base indicators. *Elec. J. Env. Agricult. Food Chem.* **2010**, *9*, 875–884.
62. Chemistry LibreTexts. Acid-Base Indicators. Available online: https://chem.libretexts.org/Courses/University_of_California_Davis/UCD_Chem_002B/UCD_Chem_2B/Text/Unit_IV%3A_Acids_and_Bases/16%3A_Additional_Aspects_of_Acid-Base_Equilibria/16.3%3A_Acid%E2%80%93Base_Indicators (accessed on 25 May 2021).
63. Parel, P.; Burnett, L.; Geoffroy, M.; Parel, J.; Hao, L. Determining the Acetic Acid Concentration in White Vinegar: An At-Home Undergraduate Chemistry Experiment During the COVID-19 Pandemic. *ChemRxiv*, 2021; submitted.
64. Fernández, S. Laboratorio Virtual. Valoración Ácido Base. Available online: https://labovirtual.blogspot.com/search/label/valoraci%C3%B3n%20%C3%A1cido-base (accessed on 1 June 2021).
65. Joshi, A.; Kale, S.; Chandel, S.; Pal, D.K. Likert scale: Explored and explained. *Br. J. Appl. Sci. Technol.* **2015**, *7*, 396–403. [CrossRef]
66. Rincón Gómez, W.A. Preguntas abiertas en encuestas ¿cómo realizar su análisis? *Comun. En Estadística* **2014**, *7*, 25–43.
67. Cortina, J.M. What is coefficient alpha? An examination of theory and applications. *J. Appl. Psychol.* **1993**, *78*, 98. [CrossRef]
68. Babinčákovaá, M.; Bernard, P. Online experimentation during COVID-19 secondary school closures: Teaching methods and student perceptions. *J. Chem. Educ.* **2020**, *97*, 3295–3300. [CrossRef] [PubMed]
69. Villanueva, O.; Behmke, D.A.; Morris, J.D.; Simmons, R.; Anfuso, C.; Woodbridge, C.M.; Guo, Y. Adapting to the COVID-19 Online Transition: Reflections in a General Chemistry Sequence Taught by Multiple Instructors with Diverse Pedagogies. *J. Chem. Educ.* **2020**, *97*, 2458–2465. [CrossRef]