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Lab at home in distance learning: A case study

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ABSTRACT

Lab work is a basic pillar, especially in engineering and science. It promotes problem solving and discovery and it has proven to enhance student learning. Transversal competences such as autonomy or effective oral and written communication are also enhanced. E-learning is currently increasing and requires a redesign of practical work. Several virtual laboratories can be found to cover different areas. This, however, does not replace the face-to-face laboratories in the field of chemistry, where students need to perform hands-on experiments to acquire the required skills. An alternative is experimentation at home. Most existing references in this regard describe qualitative experiences. In this work we have designed a home practical work in which some fundamental concepts of chemical kinetics and catalysis are developed quantitatively. Students are introduced here to wastewater treatment using an advanced oxidation process; the Fenton reaction. From the results of a preactivity survey, students showed motivation and high expectations with the activity proposal. From a post-activity survey, we concluded that the perception of students towards the activity did not change after completing it. The learning objectives were met both for the students that participated in the take-home experiment and for those who did the experiment in the laboratory.

1. Introduction

In chemistry and chemical engineering, face-to-face lab work is essential due to the importance of the handling of equipment, the preparation of solutions, etc. The study of reaction kinetics is frequent in the subjects of Chemistry, Chemical Kinetics, Catalysis and Wastewater Treatment.

Lab work is essential in the curriculum of certain degrees, especially in the areas of science and engineering (Glassey and Magalhães, 2020). It is in the lab where students test the concepts and consolidate the knowledge acquired in lectures. In addition, the lab work aims to develop general skills such as autonomy, effective oral and written communication, the promotion of research and, where appropriate, teamwork (Lavi et al., 2021).

Kirschner described three possible types of laboratories (Kirschner, 1992). The formal or traditional laboratory is the most common one: here, the student is told exactly what to do, like in a cookbook. The aim is to verify the concepts taught in lectures and results are expected. On the opposite side we find experimental laboratories, which are open-ended and are aimed at discovery. In this case the student is challenged, and instructions are general. Lastly, divergent laboratories are those in which instructions are given but problems are also introduced, and students must solve them. They are a compromise between the other two methods and can be defined as guided-discovery labs. It has been reported that the experimental or divergent laboratories could increase student motivation. In this sense, the orientation of lab work to the resolution of problems and discovery can enhance learning (Mahmoud et al., 2020; Reid and Shah, 2007).

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In the last years, distance learning has increased at the university level. This methodology offers flexibility to students, and it therefore is an option for those who, for example, work and would like to continue studying. Additionally, distance learning results in reduced costs for the University, as the need for infrastructure is lower. In Spain, in the year 2019/2020, the official degrees that were offered blended or online represented a 9.2% of the total offer. However, in science and engineering, only 3.1% of the degrees were offered in this modality (Ministerio de Ciencia Educación y Universidades, 2020). In distance learning courses, the laboratory must be taken to virtually, which is a great challenge in areas where experimentation is fundamental. It should be noted that the Covid-19 pandemic forced all institutions to move to online education immediately (García-Morales et al., 2021).

The most common employed methods to take lab work to virtuality include simulations, videos, videoconferences or synchronous sessions (De La Torre et al., 2013).

The use of virtual laboratory simulators is the most often technique employed in distance learning. Virtual labs are used in different areas and at different levels (Civitas, 2016; Green et al., 2018; Lingyun and Haijun, 2007; Makransky et al., 2016; Oliver and Haim, 2009). However, these labs do not allow the student to experience hand-on science procedures. To provide a more realistic experience, some virtual reality labs have been reported, mainly in the sanitary area (Andersen et al., 2015; Seymour et al., 2002; Valdez et al., 2013). This method often limits the application of divergent or experimental lab work because a specific software is used to guide the student. For this reason, we believe that in areas such as chemistry or chemical engineering, the use of home laboratory kits is the best distance learning option. Moreover, it has been reported that take-home experiments enhance students' scientific attitude (Zulirfan et al., 2017).

Additionally, recent research shows that, in distance learning, Chemical Engineering students prefer lab at home or simulated labwork rather than other options, such as the treatment of experimental data obtained by others (Larriba et al., 2021).

In this work, we developed a take-home experiment that enables university students to do their lab work with materials found in pharmacies, supermarkets, pet shops or hardware stores. To our knowledge, several labs-at-home have been reported, although, in chemistry, most deal with basic experimentation and demonstrations (Cash, 2021). Only few reports include university-level experiments where students are expected to obtain quantitative results regarding chemical reactions (Andrews et al., 2020; Caruana et al., 2020; Crisp et al., 2011; Kennepohl, 2007; Madriz et al., 2021). However, to our knowledge, no previous take-home experiments deal with the treatment of wastewater in a frame that resembles a real situation that can take place in industrial processes. In this sense, the take-home experiment presented here pretends to introduce university students to reaction kinetics by means of studying an advanced oxidation process (namely, photo-Fenton) to treat a simulated colored wastewater that is typically produced in several industrial processes.

We developed a questionnaire for the students to response before and after they completed the take-home experiment. Our aim was to analyze the perception of the students and their motivation towards the activity before and after completing it; and to determine whether the lab work at home could substitute face-to-face lab sessions with no side-effects on the learning process and on the acquisition of skills.

2. Methodology

2.1. PART 1: The take-home experiment

2.1.1. Introduction to the experiment

Industrial colorants are frequently employed in several sectors, such as textile fabrics or tanneries, among others. These compounds persist in aquatic environments due to their high molecular weights, complex structures and high solubility, and their presence in wastewater effluents has a great visual impact even at low concentrations of a few $mg{\cdot}L^{-1}$. Moreover, these substances inhibit the penetration of solar radiation if they reach natural water bodies and this implies serious consequences for aquatic ecosystems.

Methylene blue is an aromatic heterocyclic compound derived from thiazine, which has many applications in different fields, such as biology, veterinary and the chemical industry. This compound can be used as a dye or as an antifungal (Abrahams and Brown, 1977).

Most industrial colored wastewaters present low biodegradability and cannot be treated in conventional wastewater treatment plants (WWTPs). One of the alternatives for these wastewaters is the use of advanced oxidation processes (AOPs), that employ highly oxidant species, mainly hydroxyl radicals (·OH), to oxidize organic contaminants (Glaze et al., 1987). Among these techniques we find the Fenton and photo-Fenton processes.

The Fenton reaction is based on the generation of highly oxidizing hydroxyl radicals (·OH) by adding hydrogen peroxide, H_2O_2, to salts of iron, Fe(II) (Fenton, 1894) (see reaction 1).

$$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + OH^- + \bullet OH \quad (1)$$

The Fe(III) formed in reaction 1 can be reduced back to Fe(II) according to reactions 2 – 4, although this process is slow.

$$Fe^{3+} + H_2O_2 \leftrightarrow FeOOH^{2+} + H^+ \quad (2)$$

$$FeOOH^{2+} \rightarrow Fe^{2+} + \bullet OOH \quad (3)$$

$$Fe^{3+} + \bullet OOH \rightarrow Fe^{2+} + H^+ + O_2 \quad (4)$$

If we illuminate the reaction with UV radiation the process is called photo-Fenton. With illumination, the Fe(II) that is oxidized to Fe(III) in reaction 1 is reduced back to Fe(II) (reactions 6 and 7). Accordingly, the process becomes catalytic and requires lower concentrations of Fe(II).

$$Fe^{3+} + H_2O \rightarrow FeOH^{2+} + H^+ \quad (6)$$

$$FeOH^{2+} \xrightarrow{h\nu} Fe^{2+} + \bullet OH \quad (7)$$

The Fenton reaction is greatly influenced by pH due to the speciation of iron and the stability of H_2O_2, which are dependent of pH (Clarke and Danielsson, 1995). Therefore, preferred pH values are between 2 and 4 (where iron is found dissolved). Conductivity must also be taken into account because it can influence the speciation of iron and, thus, its solubility (Millero et al., 1995).

Lastly, the concentrations of Fe(II) and H_2O_2 must be optimized to avoid undesired reactions (see reactions 8 – 10).

$$Fe^{2+} + \bullet OH \rightarrow Fe^{3+} + OH^- \quad (8)$$

$$H_2O_2 + \bullet OH \rightarrow H_2O + HO_2^\bullet \quad (9)$$

$$HO_2^\bullet + \bullet OH \rightarrow H_2O + O_2 \quad (10)$$

The optimum Fe(II) and H_2O_2 to be added must be determined experimentally. However, some authors determine the chemical oxygen demand (COD) of the wastewater to be treated and assume that all the necessary oxygen for the removal of organic matter comes from the decomposition of H_2O_2. This gives an estimate of the concentration of H_2O_2 to be added. Next, a molar relation H_2O_2/Fe(II) between 10 and 25 is frequently adequate (Kim and Vogelpohl, 1998), although this must be determined experimentally for each particular case.

2.1.2. Reaction kinetics

For irreversible and homogeneous reactions, the mathematical model that describes how reaction rates vary with reactants and reaction conditions in general is described by Eq. (11):

$$\frac{dC_A}{dt} = r = kC_A^a C_B^b C_C^c \ldots\ldots \quad (11)$$

where:r is the reaction rate, with concentration/time units, A, B and C are the reactants and catalysts, C represents concentration, a, b and c are the partial orders of reaction and k is the reaction rate constant.

If the concentration of all substances except for one is kept constant, Eq. (11) can be simplified as follows:

$$\frac{dC_A}{dt} = r = k' C_A^a \quad (12)$$

where:k' is the apparent reaction rate constant. The units will depend on the order of reaction, and will be "concentration units"$^{(1-a)}$·"time units"$^{-1}$. For example, for first order reactions (a=1), k' will be given in "time^{-1}" units.

Eq. (12) can be linealized using logarithms:

$$\log r = \log k' + a \log C_A \quad (13)$$

To determine the reaction rate, reaction times for the consumption of reactant A must be recorded. A representation of logr vs. logC_A will result in a straight line and the slope will be equal to the reaction order for reactant A.

Note that the rate constant of a reaction, k, depends on temperature, according to the Arrhenius equation (Eq. (14)). Therefore, to apply Eq. (13), temperature should be monitored along the reaction to verify that it does not change.

$$k = Ae^{\frac{-E_a}{RT}} \quad (14)$$

where:A is the pre-exponential factor, with the same units as k, Ea is the activation energy for the reaction, in J·mol^{-1}, R is the universal gas constant, 8.31 J·K^{-1}mol^{-1}, T is the temperature in the reactor, in K.

We had the following objectives with the take-home experiment: on one hand, to introduce the Fenton and photo-Fenton processes, when they may be applied and the parameters that influence these reactions: and on the other, to determine the order of reaction for the treatment of a specific contaminant, in this case, methylene blue, using photo-Fenton.

2.1.3. Materials and reactants

The necessary materials and reactants for the home-made experiment and their equivalent for the traditional experiment in the lab are shown in Table 1.

Table 1
Necessary materials and reactants.

For experiment in the traditional lab	For the take-home experiment	Where to find it	Approximate cost
Iron (II) sulphate	Tardyferon 80 mg *	Pharmacy	3.00 €/box (30 tablets)
Hydrogen peroxide 4,9%	Hydrogen peroxide	Supermarket/ pharmacy	0.90 €/250 mL
Hydrochloric acid 20%	Salfumant	Supermarket/ hardware store	1.00 €/L
Methylene blue	Kordon Methylene blue **	Pet shop	5.00 €/118 mL
Distilled water	Distilled water	Supermarket	2.00 €/5 L
Balance with 0.01 g precision	Kitchen scale	Supermarket/ hardware store	10.00 €/unit
Volumetric flasks	Empty water bottles	Supermarket	–
Measuring cylinder	Kitchen measuring jug	Supermarket	1.00 €/unit
Dropper	Dropper	Pharmacy	0.10 €/unit
Pipette	5 – 10 mL syringe	Pharmacy	0.10 €/unit
Stirrer	Manual stirring	–	–
–	Kitchen mortar	Supermarket	3.00 €/unit
Nitrile gloves	Nitrile gloves	Supermarket	1.00 €/10 gloves
Protection glasses	Protection glasses	Workwear store	1.54 €/unit
Lab coat	Lab coat	Workwear store	- ***
Thermometer	Thermometer	Pet shop/ hardware store	2.20 €
TOTAL			30.84 €

* Box of Tardyferon tablets can be used for 3 experimental kits.
** Kordon Methylene blue can be used for 10 experimental kits. Any antifungal for aquariums can be used if the composition is 100% methylene blue.
*** The cost of lab coats is not included because chemical engineering students need this material for face-to-face labwork too.

All the materials can be found in supermarkets, pharmacies and pet stores (for methylene blue). We decided to provide a kit with the weighed methylene blue (100 mg), the iron (II) sulphate tablets, nitrile gloves, droppers and syringes to the students to reduce the cost for the students. With this kit, the total estimated cost for students of the necessary materials for the home experiment is between 7.44 and 9.44 €. The lower cost is for experiments with tap water and the higher one for experiments with distilled water. Most students will already have the necessary materials at home, (jugs, mortars, etc.) and, thus, the experience will most probably have no additional cost for them. The cost for the University is that of the experimental kits, which is about 3.24 € (plus delivery costs if necessary).

2.1.4. Procedure

First, prepare solutions of several concentrations of methylene blue: namely 100, 50, 25, 12.5, 6.25 and 3.12 mg·L^{-1}. The solutions can be prepared in translucent water bottles, using measuring jugs, and distilled or tap water can be used. Note that ions from tap water can interfere with the Fenton reaction, so the reaction rate will be different for experiments done with distilled water vs tap water. Next, acidify these solutions by adding 1 mL of Salfumant to ensure a pH lower than 4: this can be done with a 1 mL dropper or with a syringe.

The take-home experiment consists of several sections, which are detailed below.

2.1.4.1. Estimate the order of reaction for the photo-Fenton reaction. The order of reaction (for methylene blue) will be estimated by varying the initial concentration of methylene blue and keeping the rest of parameters (iron, hydrogen peroxide and pH) constant. We have checked that the addition of 80 mg of iron (II) sulphate (equivalent to one Tardyferon pill) and 5 mL of a 4.9% solution of hydrogen peroxide to 250 mL of methylene blue (up to 50 mg·L^{-1}) is enough to obtain good results. Reactors (bottles) must be placed under solar irradiation for the photo-Fenton process to take place. Note that solar radiation is a key parameter in photo-Fenton reactions and, therefore, reaction times for decolouration will depend on the intensity of the radiation. Normally, in sunny or even cloudy days, solar radiation is in excess, but all reactions

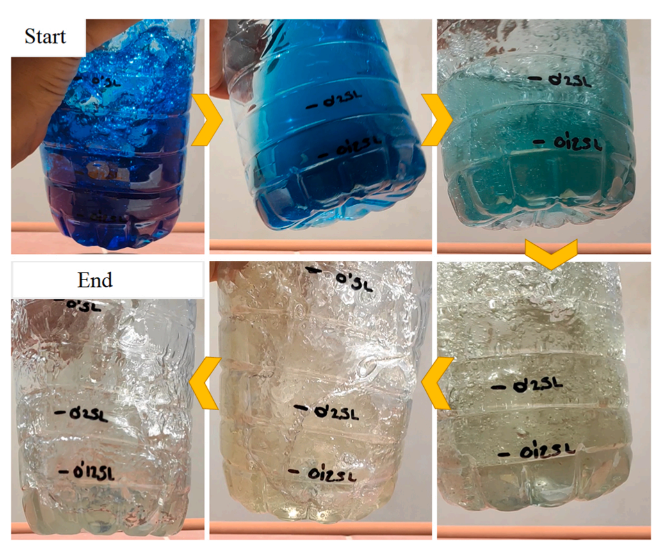

Fig. 1. Experiment for the decolouration of 50 mg·L^{-1} methylene blue with photo-Fenton.

must be done during the same day at the same time, to ensure that solar radiation is almost constant during the experiments. Fig. 1 shows the course of the reaction for 50 mg·L^{-1} methylene blue.

2.1.4.2. Effect of the concentration of hydrogen peroxide on the reaction rate. The experiment for 25 mg·L^{-1} methylene blue is repeated but, in this occasion, a different amount of hydrogen peroxide is to be added. If hydrogen peroxide is added in excess, reactions 9 and 10 will take place and the reaction rate will decrease, with a consequent higher reaction time. Similarly, if the addition of hydrogen peroxide is below the necessary amount, we will not see a complete decolouration of methylene blue because hydrogen peroxide is a limiting reagent in the photo-Fenton reaction.

2.1.4.3. Effect of solar radiation. The experiment for 25 mg·L^{-1} methylene blue is repeated but, in this occasion, the bottle is not placed under direct solar radiation. In this case, only reactions 1–4 will take place (Fenton). Consequently, an increase in reaction time will be found.

2.1.4.4. Effect of pH. In this case, the experiment for 25 mg·L^{-1} methylene blue is repeated but without acidifying the solution. The natural pH of this solution is around 7. An increase in reaction time will be observed.

Students will receive clear instructions to estimate the order of the reaction (first stage), but the rest of the experiments (effect of parameters on the reaction) will be left open-ended for them to develop these experiences.

2.1.5. Hazards

The manipulation of hydrogen peroxide, iron sulphate and methylene blue for this take-home experiment at the given concentrations does not represent a risk. Methylene blue, Salfumant (hydrochloric acid) and hydrogen peroxide are toxic if swallowed, and therefore cannot be swallowed. Students must wear nitrile gloves and safety glasses to manipulate Salfumant. However, the commercial bottle of Salfumant is designed to release its content dropwise; therefore, the risk of spills is minimal. During the photo-Fenton reaction, no safety issues are applicable.

The treated wastewater from the take-home experiment will contain mainly low-chain carboxylic acids, such as acetic acid, which can be disposed in the sewage. This final wastewater will be light yellow/ almost transparent. However, possible residues of methylene blue must be disposed at the University, in the available containers for chemicals which represent a hazard to the environment. Students can collect this residue in conventional plastic bottles.

2.2. PART 2: The survey

In order to know the opinion of students about the activity, an anonymous questionnaire together with a guide to explain the activity was sent to them. This questionnaire was completed before the activity because we wanted to know the perception and attitude of students towards a take-home experiment. The same questionnaire (with the verbs in past tense) was completed after the activity, which helped us to verify whether the perception of students changed after completing the home-made experiment.

This take-home experiment was designed for the subject of Experimentation in Chemical Engineering (last year of Chemical Engineering Degree) at a University in the Canary Islands, Spain. We believe that this experience can be extended to any subject dealing with wastewater treatment or reaction kinetics. For this reason, to recopilate enough data to validate the survey we additionally passed the pre-activity survey to students of Environmental Technologies I (second year of Mechanical Engineering Degree) and Design and Management of Industrial Chemical Processes (last year of Organizational Engineering) at a University in the Canary Islands, Spain.

Details regarding the design and validation of the questionnaire are given in Appendix 1. The final version of the survey is included in Table S2.

3. Results and discussion

3.1. The opinion of students (preactivity)

In this section we include the results from the preactivity survey that was completed by several students of Mechanical Engineering (second year), Industrial Organization (last year) and Chemical Engineering (last year).

The survey was responded by: 63 students (77% of the enrolled students) of the subject Environmental Technologies I (second year of Mechanical Engineering Degree), 15 students (75% of the enrolled students) of the subject Design and Management of Industrial Chemical Processes (last year of Organizational Engineering Degree) and 20 students (100% of the enrolled students) of the subject Experimentation in Chemical Engineering (last year of Chemical Engineering Degree) at a University in the Canary Islands, Spain. A total of 98 out of 122 surveys were responded (80%). For further details about the students that participated in this preactivity please see Table S3.

The survey results were similar for male and female respondents and for students that were enrolled for the first time in the subject vs those that repeated. Fig. 2 shows the mean scores for each item for Mechanical Engineering, Organizational Engineering and Chemical Engineering students.

The mean general score for all items was above 3. All students felt confident in doing the experimental work alone (Q5) and they found that the guide was clear (Q13). Additionally, a mean score of 3.8 was obtained when students were asked for their motivation with this activity.

The detailed response of all students for each item is shown in Fig. 3.

The number of students that agreed or strongly agreed with Q9 and Q11 was higher for Chemical Engineering students. As can be seen from Fig. 3, 90% and 65% of Chemical Engineering students met this criteria for Q9 and Q11, respectively. Only 65% and 36% Mechanical Engineering students; and 46% and 38% Organizational Engineering students responded with a 4 or 5 to Q9 and Q11, respectively. This can be related to the nature of the take-home experiment and the interests of Chemical Engineering students. In this sense, from Q9 we observed that most Chemical Engineering students showed a high predisposition to a take-home experiment. From the response to Q11 we saw that these students believed that they will acquire the same skills whether they did the experiment at home or in the laboratory. Chemical Engineering students are more familiarized with chemistry laboratory work than Mechanical Engineering or Organizational Engineering students, which may explain the differences in the response.

For all items except 1 (Q1), 2 (Q2), 3 (Q3), 4 (Q4) and 11 (Q11), less

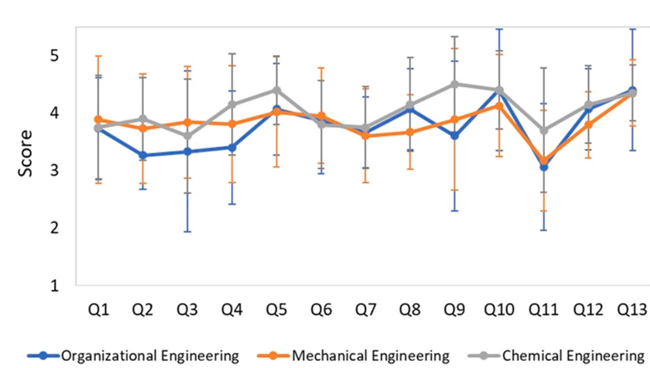

Fig. 2. Mean scores by item (preactivity survey).

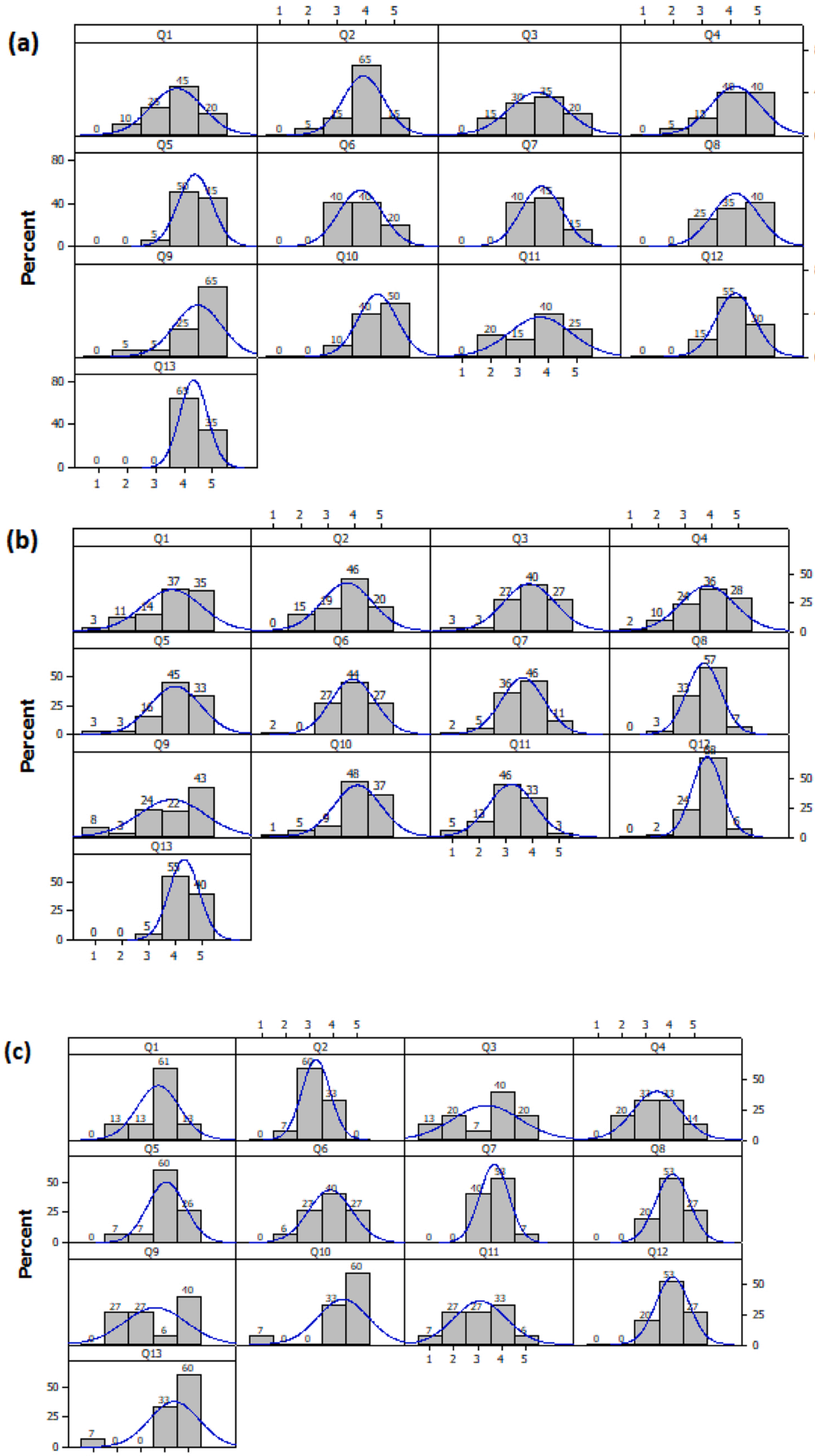

Fig. 3. Histograms of the results obtained for the preactivity survey, for each item, where 1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree; and 5 = strongly agree. (a) Chemical Engineering students, (b) Mechanical Engineering students and (c) Organizational Engineering students.

than 15% of the respondents from Mechanical and Organizational Engineering disagreed or strongly disagreed. This only occurred for item 11 (Q11) for Chemical Engineering students. Items 1 (Q1) to 4 (Q4) represent the organization factor and measure whether the students believe that the necessary materials are affordable and easily available for them to collect in one week. This could be solved by providing the students with kits. In this sense, several authors have reported positive feedback from students when home kits are provided to them (Hoole and Hoole, 2002; Kennepohl, 2007).

3.2. Experimental results

The degradation of methylene blue with photo-Fenton starts with the decolouration of the water. Generally, carboxylic acids are produced during this first stage of the reaction, and these intermediates continue the reaction with hydroxyl radicals until complete mineralization is achieved. In this work we have used an approximation to determine the order of the reaction. We calculated the average reaction rate for each experiment, r_{av}, and plotted $\log r_{av}$ vs. $\log C_{Aav}$. The average reaction rate was calculated as C_{A0}/t, being *t* the time for decolouration and assuming that methylene blue was completely consumed after decolouration. C_{Aav} is the calculated average concentration of methylene blue along the reaction, expressed as $C_{A0}/2$. We must remark that this calculation is an approximation, but good results are obtained from the experimental work. In this sense, the resulting reaction order is obtained with high R-squared values, $R^2 > 0.94$. The order of reaction reported by other authors for the degradation of methylene blue using the photo-Fenton reaction is 1 (Abhilasha et al., 2016). In this experience, values between 0.6 and 1 were obtained. Fig. 4 shows an example of the experimental results obtained by one of the students who did the experiment at home.

For the experiments to evaluate the effect of the concentration of hydrogen peroxide, we found that increasing the concentration of hydrogen peroxide to double (10 mL) doubled reaction time. This indicates excess hydrogen peroxide, and the consequent occurrence of reactions 9 and 10.

When the experiment was done in the dark, (effect of solar radiation) we found that reaction time increased by over 10 times.

Lastly, for the study at natural pH instead of pH 2–4, reaction time increased by 7.5 times. Moreover, the color of the solution at the end of the reaction remains dark yellow due to the precipitation of iron at this pH.

3.3. Academic results

The take-home experiment activity was implemented in year 2021 in the subject of Experimentation in Chemical Engineering (last year of Chemical Engineering Degree) at a University in the Canary Islands, Spain. There were 20 students enrolled in this subject. Two groups were established: a group of 5 students who did this experiment in the lab at the university with assistance from the professor; and another group of 15 students who did this experiment at home, with the take-home kit and the experiment guide included in Appendix 2. The support from the professor was given by email to those students who did the experiment at home. Students were introduced to the activity at the beginning of the course and agreed to carry it out.

With this activity we investigated whether the students would achieve the same learning objectives with both modalities: on-site labwork vs the take-home experiment.

All students delivered a report with the experimental results obtained. Only 15% of the students who did the experiment at home did not reach the correct conclusions from the experimental work.

Additionally, both sets of students were evaluated with an exam that consisted on a 5 question multiple choice test. The weight of this test on the final mark of the subject was of 5%. The exam was done at a fixed date and time online (using Moodle) for all students and the five questions were randomly selected from a question bank that is included in Table S7 (see Appendix 3). The exam was configured in the sequential navigation mode; that is, students cannot go back to earlier questions nor can they skip to later questions.

The grades for the exam varied between 1 (minimum) and 5 (maximum). The results of the exam are shown in Fig. 5. The mean grade was 3.9 ± 0.93 and 3.6 ± 1.14 for the students who did the experiment at home and in the laboratory, respectively. A two-sample *t*-test with a confidence level of 95% returned a p-value higher than 0.05, which indicated that there was no difference in the exam scores for both learning modalities (lab vs at home).

Some authors have reported that students perform at equivalent or better levels with take-home experiments than with traditional on-campus labwork (Mackay and Fisher, 2014). This agrees with the results from this study. To prevent students from having difficulty understanding some of the experimental procedures in absence of instructor assistance, audiovisual support to the instruction sheets can be used. In another study, students' perception of the laboratory instruction sheet for a remote laboratory indicated that a well-designed laboratory instruction sheet has the potential to effectively replace an instructor in terms of successfully completing the activity (Lal et al., 2020). In this case, from the preactivity survey results we saw that, all the Chemical Engineering students agreed or strongly agreed that the instruction sheet was clear (see Fig. 3a, Q13).

3.4. The opinion of students (post-activity)

Only the students who participated in the take-home experiment, that is, 15 students from the Chemical Engineering course (last year), responded the post-activity survey. This survey, as mentioned above, contained the same items as the preactivity survey, but with the verbs in the past tense. Results are shown in Figs. 6 and 7. Fig. 6 includes the

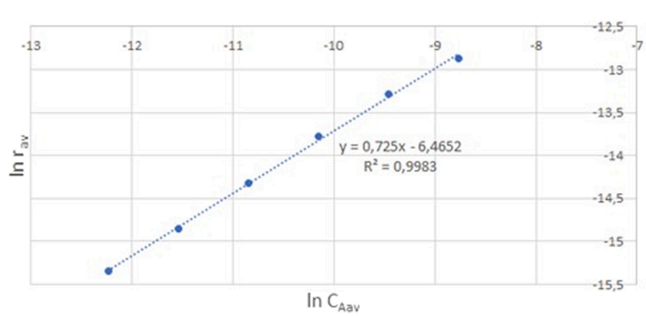

Fig. 4. Experimental results for the degradation of methylene blue with photo-Fenton. Here, r_{av} is given in $mol \cdot L^{-1} \cdot s^{-1}$ and C_{Aav} is given in $mol \cdot L^{-1}$.

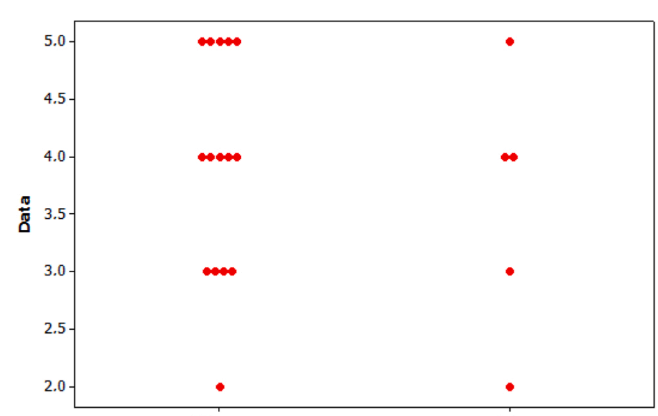

Fig. 5. Individual value plot of the exam grades of students who did the experiment at home vs those who did it in the laboratory.

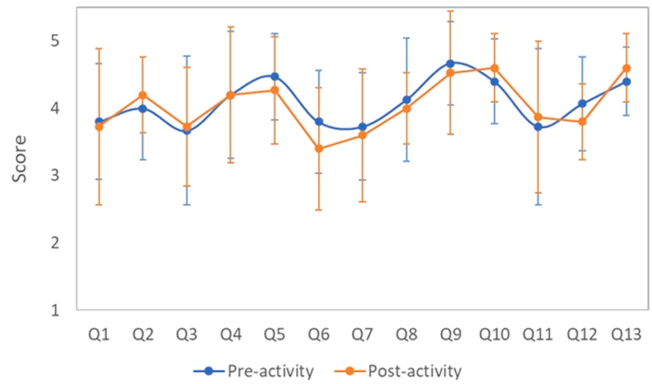

Fig. 6. Pre- and post-activity survey response.

mean scores obtained for each item in the preactivity vs post-activity surveys, considering only the response of the students that participated in the take-home experiment.

A paired *t*-test with a confidence level of 95% returned a p-value higher than 0.05 for all pre and post-activity survey items, which indicated that there was no difference in the results from the pre- and post-activity surveys; that is, in general, the students did not change their perception of the take-home experiment after completing it.

If we compare Figs. 3a and 7 we observe that after providing the experimental kit, no students believed that collecting the material was a problem (Q2 and Q3). However, 13% of the students still needed to invest some money in materials to carry out the take-home experiment (Q4). Specifically, some students indicated that they did not have a mortar nor Salfumant at home and needed to purchase these. For future editions, this could be solved by providing some hydrochloric acid to the students in a sealed recipient and changing the Tardyferon tablet for an encapsulated pill containing liquid o powdered ferrous sulphate. Additionally, the percentage of students who indicated that the conditions at home were not appropriate for the experiment increased from 10% to 14% after completing the activity (Q1).

On the other hand, regarding motivation and expectations, 13% and 14% of the students, respectively, revealed in the post-activity survey that their motivation in the subject was not increased after doing this activity (Q6) and that their knowledge was not enhanced (Q7). However, 40% of the students felt that the activity increased their interest in the subject after completing it.

Regarding capacity, 79% of the students considered that the skills acquired with the take-home experiment were equivalent to those that they would have achieved in the laboratory (Q11); 65% of the students believed this before doing the activity. Finally, all students (Q13) believed that the instruction sheet was clear both before and after the activity, which, in our opinion, is a crucial aspect for the success of the activity.

In general, according to the pre- and post-activity survey results, the students evaluated positively the take-home experiment.

4. Conclusions

In this work we pretended to adapt face-to-face practical teaching to distance learning. In this sense, there are several virtual laboratories, including some at the university level, which aim to bring the student closer to the laboratory through the use of videos and even virtual reality. However, we intended not to lose sight of the students' contact with face-to-face experimentation in chemistry, which is especially important for acquiring skills in the laboratory. That is why we focused

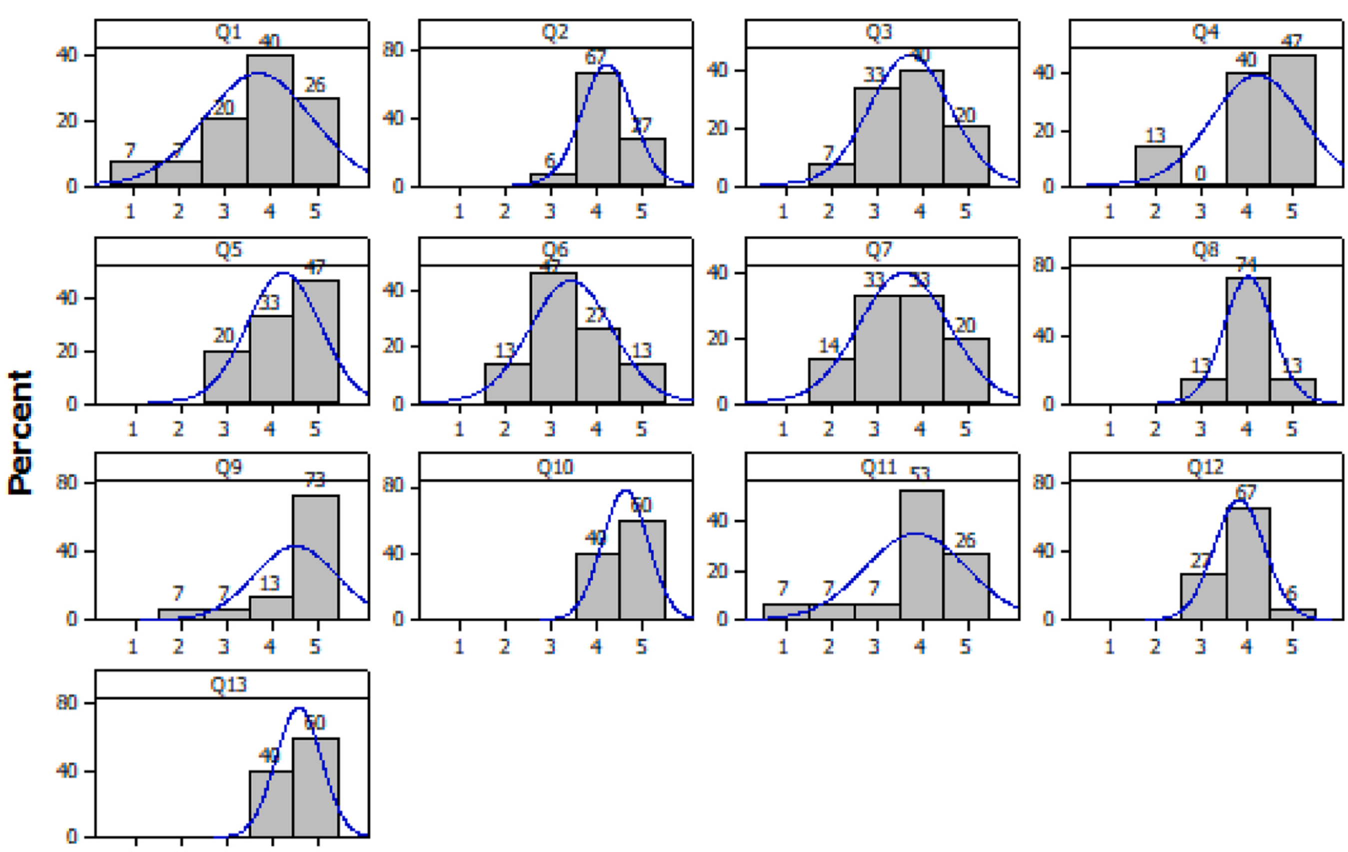

Fig. 7. Histograms of the results obtained for the post-activity survey, for each item, where 1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree; and 5 = strongly agree.

on the so-called take home experiments. There are several references in this regard, although most at the qualitative and concept demonstration level.

In this work we have designed a take home experiment for university students in the areas of environmental engineering, chemical kinetics and/or catalysis with which students can obtain results comparable to those obtained in the laboratory for the quantitative analysis of data. This experimentation is intended to provide students with knowledge in advanced oxidation techniques as an alternative for the treatment of wastewater that cannot be treated by conventional wastewater treatment methods due to its low biodegradability.

The students had to use materials which can be easily found in hardware stores, pharmacies, pet stores or supermarkets. The estimated cost for the student is between € 7.44 and € 30.84. The lowest cost involves sending a kit with several reactants and materials, to the homes of each student.

A preactivity questionnaire was desgined and validated. This survey was sent to the students to assess their predisposition and motivation towards carrying out this activity. Students showed good motivation and expectation towards the proposal of this activity, although kits may be delivered to them in order to help with the organization of the experimental work.

The evaluation of the performance of the students participating in the activity versus a control group indicated that learning objectives and experimental results were obtained indistinctly at the laboratory or at home.

A postactivity survey equivalent to the preactivity survey, responded by the students that completed the take-home experiment showed that the general perception of students on the activity did not change after completing the activity.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ece.2022.05.001.

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