Hands-on and Virtual Laboratories to Undergraduate Chemistry Education: Toward a Pedagogical Integration

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***Abstract* — Several researchers report that practical experimentation arouses a strong interest among students in Chemistry learning. Also, the classes held in didactic laboratories enhance the learning ability of the students, because they help the understanding of the subject matter. There are also reports stating that students feel more motivated to learn Chemistry when they make use of practical and dynamic classes. However, the availability of laboratories to carry out practical activities is difficult to found in different levels of education in several countries. This paper assumes that the expansion of resources to increase the experimental practice of Chemistry can be achieved by developing virtual laboratories in a way of helping them to get involved in active learning. In this work a virtual laboratory, called VirtuaLabQ, with predefined experiments about Chemical Transformations is introduced. Also, a case study that shows the use of VirtuaLabQ integrated to hands-on laboratory is presented. The case study was performed with Engineering undergraduate students that attend the Chemical Transformation course. The main target of this study was to investigate if practicing the experiments previously in VirtuaLabQ improves the students' performance in experiments accomplished in a hands-on chemistry laboratory. Two sets of laboratory experiments were conducted, in wich students first performed online activities in VirtuaLabQ and after in the hands-on laboratory, during regular class time. Also, students answered questionnaires evaluating the performance of each experiment in virtual and hands-on laboratory. Four questions were chosen to be analyzed in order to check the main target of this work. Results indicate that the integration of virtual and hands-on experiments in a Chemistry undergraduate course assists in the good performance of students in a hands-on laboratory and can contribute to the improvement of student learning. However, improvements in VirtuaLabQ and new case studies are necessary to confirm these findings, considering, for example, other kind of evaluations that effectively compare student performance besides self-evaluation.**

Keywords – Virtual Laboratory, Chemistry Education, Hands-on Laboratory, Blended Learning.

I. INTRODUCTION

According to Nunes and Adorni [1], the students had shown the difficulties to learn the subjects related to Chemistry. The modification and the lack of interest in chemical are one of the correspondence problems. Many students report that the study of Chemistry is limited to memorize several formulas, properties and chemical equations. In addition, professors also find difficulties to relate the content studied in theory with practice. Therefore, one way to awaken this interest is to bring the theory presented in class with events that happen in daily lives.

In order to facilitate the students' understanding of the subject matter, the professors know that the chemistry experiments awake their interests and the didactic laboratory increase their learning ability [2]. Almeida et al. [3] acknowledged that these experiments facilitate the understanding of the science of nature concepts, assist in the development of scientific attitudes and investigate the non-scientific concepts, as well as sparking interest in science. Finally, the authors show that students feel more motivated to learn Chemistry, when the classes are practical and dynamical.

Silva [4] explains that the constant changes of humanity are going to negatively affect the teaching process of Chemistry. It is possible to highlight the following points: (i) the methodology in the classroom can be considered outdated; (ii) few experimental classes; (iii) students lack of interest, among others.

In order to motivate and awaken the students in the understanding of Chemistry, some professors are not worried to change the traditional classes with more attractive methodology. However, these methods can also become inefficient and unattractive. According to Silva [2], the lack of practical classes is the main disinterest of the students in the learning process. Thus, the practical becomes essential to the students to verify why and how chemical phenomena occur.

The lack of equipment and the cost of maintenance can be considered the reasons to justify the reduction of classes in the laboratory. Some professors are not able to make the experiments, and there is no technical staff in the laboratories. Thus, without a physical hands-on laboratory, some works are trying to develop virtual tools to help in the teaching and learning of Chemistry.

Another point to be considered is that virtual laboratories can help make better use of hands-on labs. Gregory and Trapani [17] state that students who are well prepared for laboratory classes are more likely to successfully acquire laboratory skills and gain the maximum possible benefit from the laboratory learning environment.

This paper assumes that the expansion of resources to increase the experimental practice of Chemistry can be achieved by developing virtual laboratories in a way of helping them to get involved in active learning. It is important to point out that these laboratories do not require the technical staff and neither to purchase equipment and materials, such as glassware, reagents, among others.

Therefore, the VirtuaLabQ was developed. It is an environment with predefined experiments about Chemical Transformations. Also, the gamification elements were used to increase students' motivation [21].

This paper aims to present a case study that shows the use of the VirtuaLabQ integrated to hands-on laboratory. The case study was performed with Engineering undergraduate students that attend the Chemical Transformation course. The main target of this study was to investigate if practicing the experiments previously in the VirtuaLabQ improves the students' performance in experiments accomplished in a hands-on chemistry laboratory.

The paper is organized as follows. The Section 2 presents the background and related work. The VirtuaLabQ is briefly described in Section 3. The case study design is described in Section 4 and its results and discussions are presented in Section 5. Learned lessons are depicted in Section 6. Finally, the conclusion and future work are discussed in Section 6.

II. BACKGROUND AND RELATED WORK

In order to understand the conceptual foundations of this work, this section presents the Virtual, Hands-on laboratories and the Practice of Chemical Transformation. After that, some related works are presented.

A. Hands-on and Virtual Laboratories

Physical or hands-on investigations provide opportunities for students to interact directly with the material world using the tools, data collection techniques, models, and theories of science. Computer technologies now offer virtual laboratories where investigations involve simulated material and apparatus The value of physical laboratories for science learning is generally recognized but the value of virtual, simulated alternatives for hands-on physical laboratories is contested [18]. Therefore, these kinds of laboratories are important to be investigated in educational context.

A virtual laboratory brings many advantages. For example, it is possible to perform dangerous experiments without endangering yourselves or others. After developed the environment, the user is able to realize the experiment many times at no extra cost [5]. The laboratory improves student learning, because they perform and observe in real time the experiment in the environment. Also, it can be used for distance learning education.

The equipment required to perform the hands-on laboratory is physically set up and the students who perform the laboratory are asked to be physically present in the laboratory [6]. Therefore, it is difficult and costly to maintain and support laboratory equipment.

The virtual and hands-on laboratories have their own characteristics. However, some researchers suggest that virtual experiments used with hands-on experiments in real world may provide the best experience [5]. Thus, the mix of virtual and hands-on experiments is defined as blended instruction. These combinations have increased student's performance, because the previous knowledge is obtained in the virtual laboratory. Also, the students are free to carry out several tests, create scenarios and verify the behavior in the simulation environment, before the hands-on laboratory.

B. Practical of Chemical Transformations

VirtuaLabQ was developed based on the curriculum of the Chemical Transformations. This course is attended for all 1500 students who entered in the Bachelor of Science and Technology course at Federal University of ABC (UFABC), Brazil. The main reasons to choice this course is: (i) its practical approach; (ii) the possibility to use the VirtuaLabQ.

According to Ribeiro [13], the Chemical Transformations course aims to: (a) provide the basic chemical fundamentals to understand the phenomenon that involves the relation between the transformations that occurs in the natural environment and the properties of the materials involved; (b) correlate the macroscopic properties of materials with microscopic properties, allowing the students to know the role of Chemistry in Science, its importance in society and also in daily life; (c) introduce the basic laboratory techniques..

The bibliography of the course consists of the following authors: Atkins e Jones [14], Kotz, Treichel e Weaver [15] e Brady, Russell , e Holum [16]. In addition, the duration of the course is twelve weeks and the practical activities involve four experiments described in Table I and also in [13].

TABLE I. PRACTICAL ACTIVITIES IN CHEMICAL TRANSFORMATIONS

Practical Experiments	Involved Topics
Similar dissolves similar?	Chemical Bonds, Molecular Interactions, Chemical Reactions
Airbag production	Chemical Reactions, stoichiometry
Heating water in a camping	Heat involved in chemical transformations (Enthalpy). Heat transfer
Speed reactions	Chemical Kinetics. Laws of speed reactions

C. Related Work

Brewer et al. [7] describes the strategies to develop two new blended, distance laboratory courses using hands-on, home experimental kits and online instruction and assessments. These courses involve mixed modes of delivery, developing online course management and assessment, virtual experiments, hands-on experimentations and remote laboratory opportunities. About home experimental kits, they decided to work with a commercial kit instead of develop their own home experimental kits containing all the chemicals, glassware, and materials necessary to perform the course lab. However, they developed online multimedia resources, including videos and photographs to aid the distance learner. These resources demonstrated and emphasized proper safety procedures and laboratory techniques [7].

The Athabasca University delivers its courses 100% online and at a distance. Assuming that laboratory is required for a particular chemistry course the key question is, how the students accommodate this at a distance? Athabasca University has employed virtual, remote and home-study laboratories in their distance courses in Chemistry. Moreover, the students are asked to attend supervised regional centers on weekends or one-week sessions in the summer vacations [8].

The remote control laboratories allow the students to operate a real-life laboratory without costly equipment. However, the infrastructure to maintain them is substantial and cannot completely replace all experiments, especially the "wet" chemistry [8]. The idea for the home-study laboratory proposed in Kennepohl [8] is to enable students to carry out real experiments in the kitchen home environments, i.e. experimentation can be done with household items and ingredients. These experiments are considered a warming up hands-on laboratories at home.

Bertolini et al. [9] developed an interactive virtual laboratory, known as iLaboratory, to make the chemistry experiments. The main idea of this work is to enable the students for playing some experiments, interactively, using a smartphone. For example, the flame tests for identification of cations, precipitation reaction, among others.

The 3D Virtual Laboratory explained in [10] is another technology used to help the students to become more familiar with the items or apparatus available in a hands-on laboratory. Nunes et al [11] propose another virtual laboratory build on OpenSimulator (OpenSim) for Chemistry in a 3D virtual world. OpenSim is an open source multi-platform, multi-user 3D application server. It can be used to create a virtual environment (or world) which can be accessed through a variety of clients, on multiple protocols [22].

In Dalgarno et al [12], a virtual chemistry laboratory developed at Charles Sturt University (CSU), based on an accurated 3D model of the Wagga Wagga undergraduate teaching laboratory is used in their campus.

Tati and Ayas [23] examined the effect of a Virtual Chemistry Laboratory (VCL) on student achievement. It was concluded that the developed VCL software is at least as effective as the real laboratory, both in terms of student achievement in the unit and students' ability to recognize laboratory equipment.

TABLE II. COMPARATIVE ANALYSIS OF RELATED WORK

Comparative Parameters	Related Work
3D Virtual Lab	[5], [10], [12], [11]
Online Learning	[6], [7], [8], [9], [23]
Hands-on Lab	[7], [8], [23]
Home Kits	[7], [8]

Table II shows a comparison matrix of works referenced in this paper, and the parameters used during this analysis, mainly the pedagogical approach and instructional materials.

III. VIRTUALABQ ENVIRONMENT

This section presents the VirtuaLabQ environment with its architecture and features. More details regarding to the environment can be found in Ramos (2015) [20].

The diagram shown in Fig. 1 presents the overall architecture of the environment. VirtuaLabQ is composed of two main areas: (A) Student Module, in which the student performs experiments and (B) Teacher Module, in which professors use the logs and ranking, in order to follow the students' achievements results,

In order to facilitate the user access in VirtuaLabQ, the student sign-in the environment through its user on facebook social network (see mark 1 in Fig. 1).

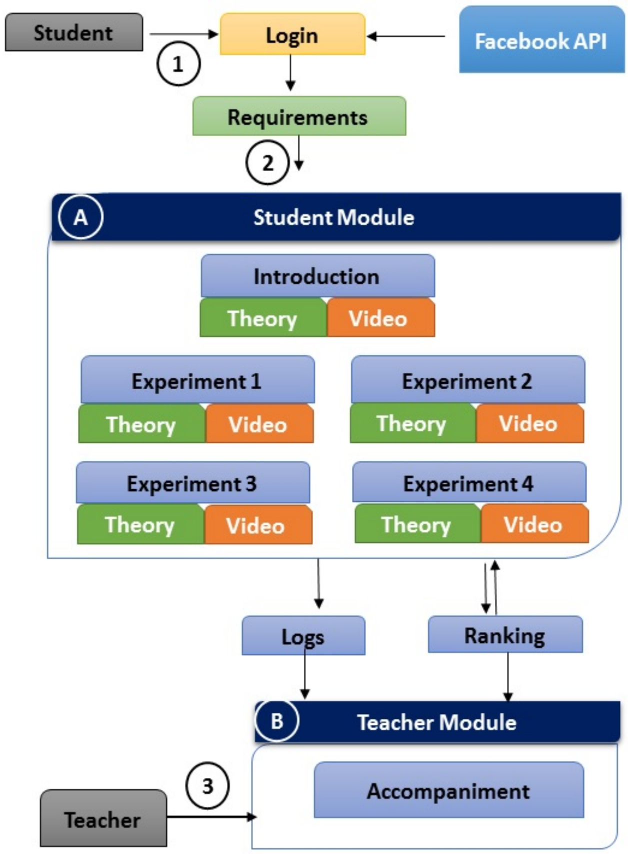

Fig. 1. General Architecture of VirtuaLabQ

After logged in VirtuaLabQ, it is mandatory that students check all requirements to perform some experiment. This corresponds to the mark 2 in Fig. 1. A screenshot of the screen requirements is shown in Fig. 2. Some of the items to be marked are for example, close the shoes, sanitize the hands, among others. These are the same requirements to enter the hands-on laboratory. This is a form of call attention of student for safety questions even in a virtual laboratory.

Fig. 3 shows the Main Menu screen, where elements as the user name, score, your avatar or photo are displayed. A menu allows the user to choose options from a list of experiments that can be performed.

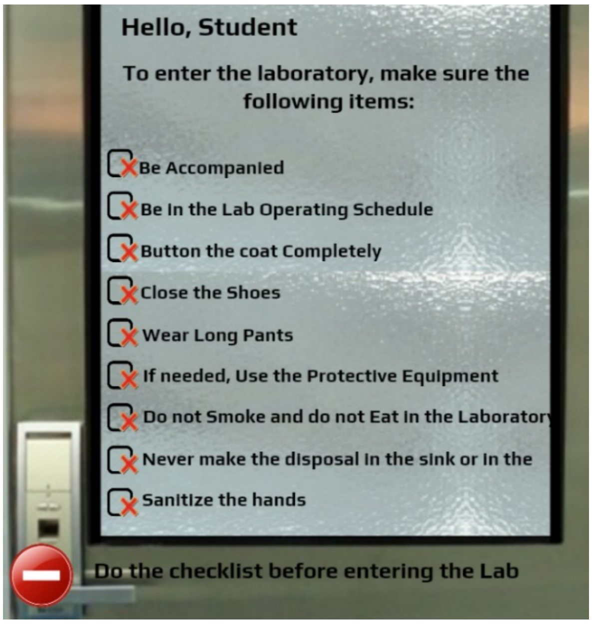

Fig. 2. Requirements to perform experiments in VirtuaLabQ

To perform each experiment, the user must follow the instructions, choose the appropriate containers and put the required substances into them. As a result, VirtuaLabQ displays an animation of the reaction and also a feedback. At the end of the experiment, the student must answer a summative evaluation regarding to the experiment.

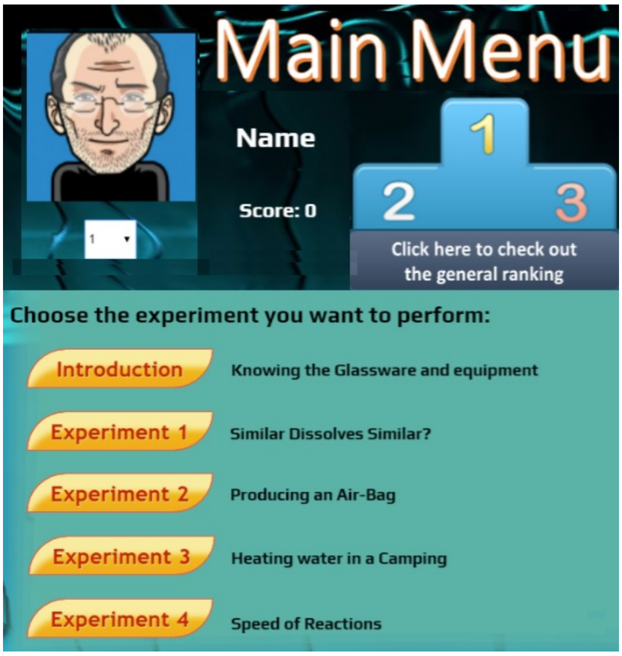

Fig. 3. Main Menu of VirtuaLabQ

At the end of each experiment, the students answer a multiple-choice questionnaire, for example in Fig. 4. The main idea is to know their level of knowledge on the experiment topics. After that, VirtuaLabQ shows their score and each student position in the ranking.

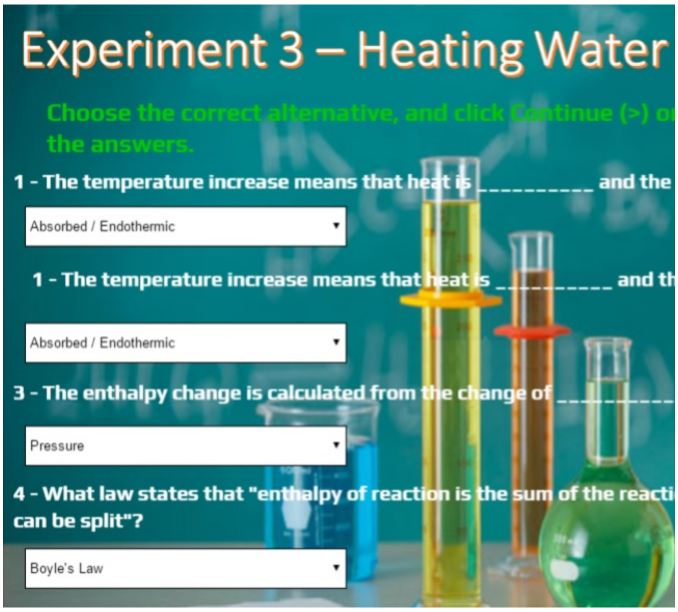

Fig. 4. Sample of Knowledge Assessment Screen

More details on how the environment works will be presented in the next section.

IV. Case Study: Experimental Design

The main research hypothesis of this work is: "Practicing the experiments previously in the VirtuaLabQ improves the student's performance in experiments accomplished in a hands-on chemistry laboratory". To test this hypothesis, this section presents a case study that was undertaken early in 2015. The main target of this study was to show the use of VirtuaLabQ as a useful virtual laboratory environment in the course. It is used for Engineering undergraduate students that attend the Chemical Transformation course at UFABC.

A. *Participants and Context*

The study was carried out in four classes with 30 students in each class, totally 120 students. These students were invited to participate in the case study, and 32 students agreed to perform the activities. After filling an informed consent form, background information about the participants were stored in a database, allowing to draw a general students' profile. For instance, 75% and 25% are male and female students, respectively. Most of participants (93.75%) had never taken the course, and 6.25% had already taken the course at least once.

The students were asked to use the VirtuaLabQ before make the experiments in the hands-on laboratory, and also filling out an appropriate questionnaire for each experiment made in different laboratories (virtual and hands-on).

B. *Instruments and Data Collection*

To collect data, two questionnaires were developed. After completing each experiment in VirtuaLabQ, the students were invited to answer the first questionnaire with 15 questions, organized in five groups: (i) access to the virtual laboratory; (ii) instructional resources such as supporting material and explanatory videos about the experiments; (iii) virtual laboratory quality and its usability; (iv) self-assessment about the experiments conducted; (v) contributions of the virtual laboratory usage.

The second questionnaire was answered immediately after the completion of each experiment in the hands-on laboratory, with 10 questions related to the following topics: (i) contributions from the experiment in the virtual laboratory, (ii) similarities and differences between the virtual and hands-on experience (iii) use of the materials available in the hands-on laboratory (iv) self-assessment about the experiments conducted. The answers of all questions in both questionnaires were based on a five-point Likert scale.

C. *Experiments in the Virtual and Hands-on Laboratories*

Two laboratory experiments were conducted, based on the following main steps: (i) Firstly, for each experiment the activities were performed in VirtuaLabQ; (ii) Students answered the questionnaire evaluating the performance of each experiment in VirtuaLabQ; (iii) After using VirtuaLabQ, the experiments were performed in the hands-on laboratory, during regular class time; (iv) Students answered the questionnaire evaluating the performance of each experiment in the hands-on laboratory.

A brief description of the two experiments conducted in the case study is presented in the next subsections.

1) *First Experiment: Heating water in a Camping*

The objective of this experiment was to verify Hess's Law for the enthalpy and entropy of a chemical reaction. To achieve this target, the students were asked to heat some water at room temperature to 400C. This experiment involved two activities:

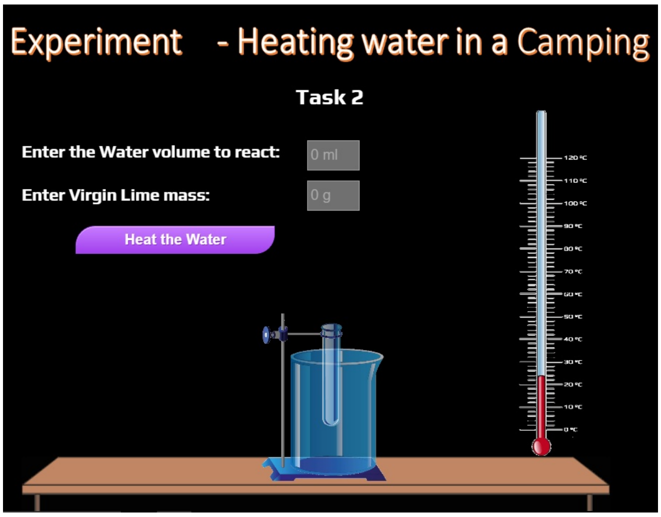

Fig. 5. Heating water in a Camping: first activity

- First Activity - Students analyzed the reaction between magnesium oxide and water and between magnesium hydroxide and hydrochloric acid, to prove Hess's law. In this activity, students calculated the required amount of each of these elements to generate sufficient heat release for heating the water in the beacker. Fig. 5 illustrates this activity in VirtuaLabQ.
- Second Activity - Students performed calculations to determine the amount of calcium hydroxide (CaO) which, when reacted with water in a beaker glass, transfers enough energy to heat indirectly 10ml of water standing in a test tube, as shown in Fig. 6.

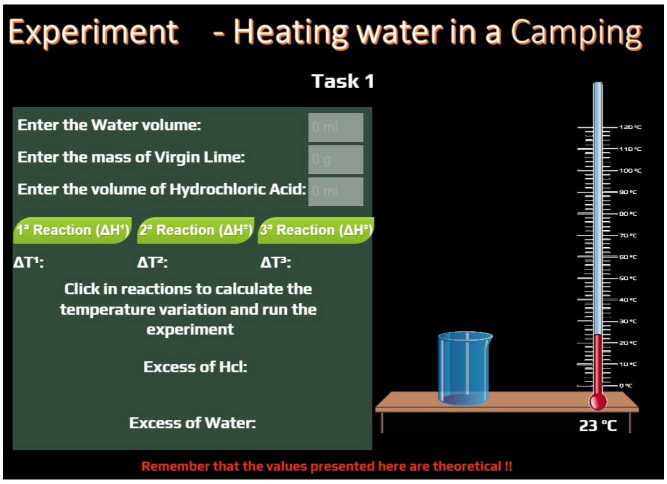

Fig. 6. Heating water in a Camping: second activity

2) *Second Experiment: Speed of Reactions*

In order to occur a chemical reaction, it must take place collisions between molecules of the reagents, with sufficient energy to break their links and form new connections. Taking this into account, the objective of this experiment was to analyze how external factors change the frequency of collisions between reagents in a chemical reaction, increasing or decreasing the speed collisions. This experiment involved two activities:

- First Activity - Students built a line graph correlating the reaction time between sodium thiosulfate and hydrochloric acid, varying the concentration of thiosulfate, as shown in Fig. 7.

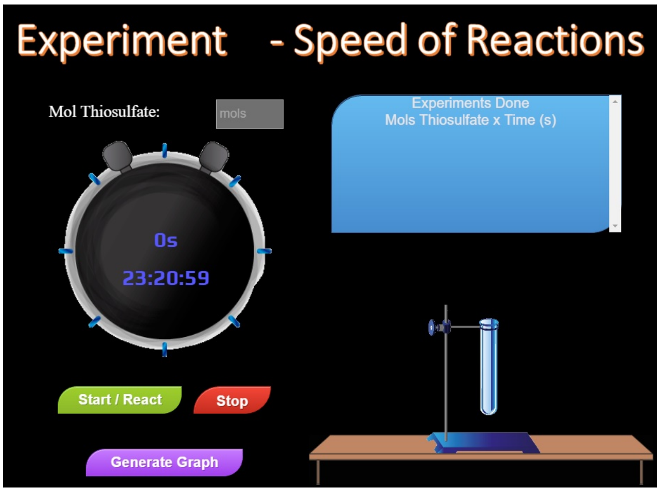

Fig. 7. Speed of reactions: first activity

- Second Activity – Fig. 8 shows the activity performed in VirtuaLabQ when the students observed the influence of homogeneous and heterogeneous catalysts in the reaction of decomposition of hydrogen peroxide. To this end, they analyzed the decomposition of hydrogen peroxide in the presence of certain compounds or solutions (catalysts).

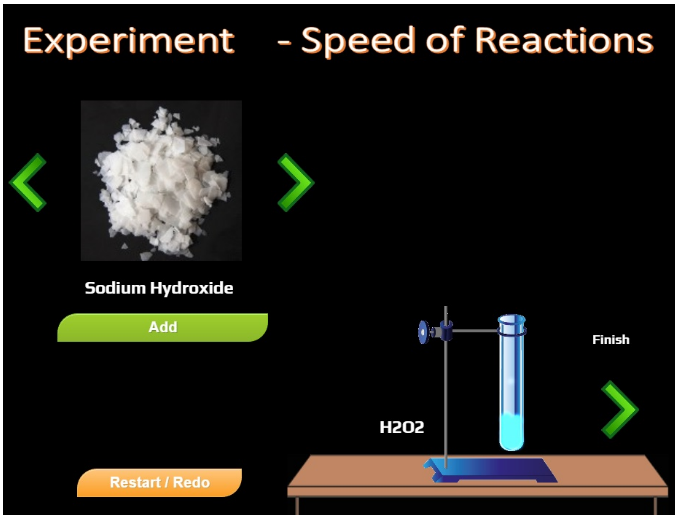

Fig. 8. Speed of reactions: second activity

V. Results and Discussions

This section deals with the results and analysis of the data gathered from the case study presented in Section III. In each experiment, the students answered 15 and 10 questions related to the virtual and hands-on lab, respectively. A set of these questions was chosen to be analyzed in this section. Also, to facilitate the understanding, the results are organized and shown in two topics: (a) contributions of VirtuaLabQ in the students' learning process and (b) integration between the virtual and the hands-on laboratory.

A. Contributions of VirtuaLabQ in the Students' Learning Process

Two questions, presented in Table III, were chosen in order to identify the contributions of activities in virtual laboratory in the learning process.

TABLE III. VirtualLabQ Contributing to the Learning process: Questions Analysed.

Id	Question
Q1	What is your level of understanding regarding the results of the experiment, establishing a nexus relationship between the data reported and the results presented by VirtuaLabQ?
Q2	Evaluate the contribution of doing the experiment in VirtuaLabQ for your learning and how you estimate it will help in your performance when doing the experiment in hands-on laboratory.

As shown in Fig. 9, 69% of students (sum of excellent, very good and good), reported in Q1 that they were able to understand the effects of experimental variables and antecedent conditions in the generation of the results of the experiments. This result indicates that the VirtuaLabQ helped in the construction of chemical knowledge of them, acting as a virtual mediator in the learning process. However, 31% of students (sum of fair or poor), answered that they have a low or no understanding of the results presented. These findings suggest that there are limitations in the virtual laboratory environment that affect the results of experiments. For example: (i) the limited handling equipment, (ii) the inability to measure some factors that influence the experiment as the ambient temperature and energy transfer to the equipment. These limitations need to be worked on a new version of the system.

Fig. 9. Results of Q1

Fig. 10 exhibits that 79% of students, in Q2, considered that the experiments in the virtual laboratory would contribute positively to their learning and performance in the hands-on lab (sum of excellent, very good and good).

This data was collected immediately after the completion of each experiment in virtual laboratory and before the hands-on lab. So this is a metacognitive metric that indicates an expectation of students in relation to their performance. This result indicates that the previous activity in the virtual lab creates a positive expectation on students regarding studies and preparation for the following activities. The 25% who answered fair or poor contribution seem to indicate that the tool needs more complex elements or that are closer to the reality of the hands-on lab.

Fig. 10. Results of Q2

B. Integration Between Virtual and Hands-on Laboratory

Two questions, presented in Table IV, were chosen in order to analyze the integration between virtual and hands-on laboratory.

TABLE IV. INTEGRATION BETWEEN VIRTUAL AND HANDS-ON LABORATORIES: QUESTIONS ANALYZED

Id	Question
Q3	Evaluate the contribution of having carried out the experiment in VirtuaLabQ for your performance when replicating it in hands-on laboratory
Q4	Compare your performance at the hands-on in relation to your performance in Virtual Laboratory

In Q3, as shown in Fig. 11, 87% of students indicated as good or very good, the contribution to have performed the experiment in VirtuaLabQ for their performance in hands-on laboratory. On the other hand, for 13% of the students having performed virtual experiments first had little influence on their performance in hands-on laboratory. This data was collected after performing the hands-on lab. This result confirms the expectations of students regarding the contribution of the previous activity in the virtual laboratory for their performance in hands-on. In fact, 13% indicated poor contribution in Fig. 11 that can be understood as equivalent to 12% of poor contribution in Fig 10.

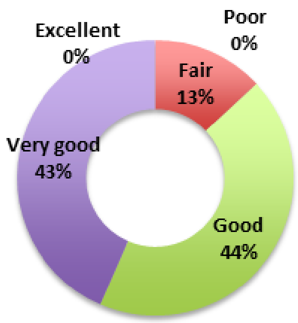

Fig. 11. Results of Q3

In Q4, as shown in Fig. 10(b), 57% indicated that performance in hands-on improved when compared to the performance in virtual and 39% stated that the performance was similar. This results indicate that VirtuaLabQ contributes to the improvement of student learning process and consequently to increase their performance with the possibility of training in the virtual lab before performing the experiments in hands-on. Obviously, the confirmation of these results requires other types of assessment (summative) that effectively compare student performance (before and after) and not only considering self-evaluation as described. The 4% who indicated a worsening in performance shows that the VirtuaLabQ needs elements that dialogue with the student about the results, in order to improve their understanding and their metacognitive awareness.

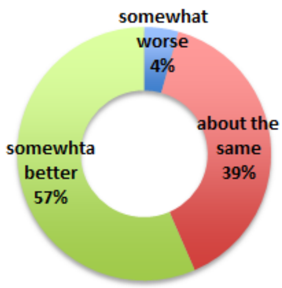

Fig. 12. Results of Q4

VI. LESSONS LEARNED

During the case study, the main hypothesis of this work was proven to be correct. Also, the results point out that the sequence of virtual and hands-on experiments in a Chemistry undergraduate course helps the students performance in a hands on laboratory.

The first result to be highlighted is that the usage of the VirtuaLabQ leads the students to familiarize with the environment of a chemistry lab, before to go to the hands-on laboratory. Second, the sequence virtual-real experiments promoted a meaningful learning, with enhancing student conceptual understanding. According to Ausubel [19], in the meaningful learning a content needs to integrate what students already know, which may be expressed by other symbols or by other words, in different contexts. That is, if learning is meaningful, and not mechanical, the individual will be able to express the new knowledge even in a different context where this concept was first learned, in this case, the virtual laboratory. Then, the integration between virtual and hands-on laboratories allows the significant learning because it leads students to transfer and use the chemistry concepts in two different contexts, helping students to generalize and synthesize the knowledge.

The extent of the findings points that the virtual experiments can cause a loss of touch with reality. Then, there is a need to bring closer and to bridge the virtual experiments to a more sense of reality. This can be done by applying an array of technologies to support learning, providing a rich context and multi-sensory experiments.

VII. CONCLUSIONS AND FUTURE WORK

There are several projects investigating ways of increase the use of practical experimentation in Chemistry learning. Its results involve different methods of teaching Chemistry: 3D Virtual Lab, Online Learning, Hands-on Lab, Home Kits, among others.

This work assumed that practicing chemistry experiments previously in a virtual laboratory improves the students' performance in hands-on laboratory. So, a pedagogical integration between virtual and hands-on laboratory should be considered.

A case study that integrates the activities in a virtual (VirtuaLabQ) and a hands-on laboratory was performed with Engineering undergraduate students that attend the Chemical Transformation course. Data was collected when the students used first the VirtuaLabQ. A few days later, the same experiments were repeated in the hands-on laboratory.

Results showed that 87% of students estimated the benefits of performing in VirtuaLabQ for their success in hands-on laboratory. However, 57% indicated that their performance in hands-on improved when compared to the performance in virtual. These results indicate that the integration of virtual and hands-on experiments in a Chemistry undergraduate course assists in the good performance of students in a hands-on laboratory and can contribute to the improvement of student learning. Obviously, the confirmation of these results requires other types of assessment (summative) that effectively compare student performance (before and after) and not only considering self-evaluation as described.

On the other hand, 13% of the students reported that performing virtual experiments first had little influence on their performance in hands-on laboratory. So, it indicates that the VirtuaLabQ needs elements that dialogue with the student about the results, in order to improve their understanding and metacognitive awareness.

Regarding the results that indicate similar performance in both environments or little influence in performing the experiments previously in VirtuaLabQ, this may be related to some limitations of the environment, such as: (a) inability to deal with the purity of the reagents or manipulate the concentration of reagents; (b) inability to deal with the environment temperature and the transfer of energy among devices; (c) reduced interactivity in handling the equipment, as in hands-on lab.

As future work, it is considered: (a) implement features in VirtuaLabQ to approach the realism of virtual experiments and hands-on; (b) the elements of dialogue with the student during his choices to check their understanding should be included in VirtuaLabQ; (c) carry out new case studies to measure the gains of the integration of virtual and hands-on laboratories, considering cognitive and metacognitive learning metrics.

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