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Virtual Chemistry Laboratory: a didactic alternative to the teaching of Organic Chemistry

Laboratório Virtual de Química: uma alternativa didática para o ensino de Química Orgânica

Laboratorio Virtual de Química: una alternativa didáctica para la enseñanza de Química Orgánica

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Abstract

Information and communication technologies (ICTs) are ubiquitous in our everyday lives as well as in educational contexts, much more so after the onset of the Covid-19 pandemic. The use of ICTs in education, e.g., virtual laboratories, is of great importance to support the teaching of chemistry. Given the difficulties secondary school students encounter in understanding organic chemistry topics, this research aimed at investigating whether the use of a software program could improve teaching and promote student learning of content related to organic compounds. To this end, the data were collected by means of a pre- and a post-intervention questionnaire. The study was conducted at a public secondary school in Itacoatiara, AM, Brazil, with 3rd-year (final year) students. The software programs IrYdium Chemistry Lab, LAPEQ-USP (Laboratory of Research in Chemistry Teaching and Educational Technologies, University of São Paulo), and Simulations for Chemistry were employed to introduce the participating students to a chemistry lab and to simulate lab practices involving chromatography experiments. The analysis of the collected data suggests that the use of virtual labs promoted the participants' motivation to learn organic chemistry as well as ability to integrate concepts taught in

the classroom to aspects of their everyday lives. The participating students also reported that they would like to use other virtual lab programs to study chemistry, thus constituting new ways of learning beyond the classroom.
Keywords: Software; Simulations; Teaching; Experiments.

Resumo

As Tecnologias da Comunicação e da Informação (TIC) estão presentes em nosso cotidiano e no contexto de pandemia foi bastante inserido no ambiente educacional. Nesta aproximação entre tecnologias e o ensino, os Laboratórios Virtuais com a utilização de softwares educacionais tem importância fundamental como uma ferramenta de auxílio e suporte no ensino de química. Considerando a grande dificuldade que muitos alunos encontram em compreender os conteúdos da disciplina Química Orgânica, abordada para a 3° série do Ensino Médio, este trabalho teve como objetivo investigar como a utilização de um software na disciplina de química pode enriquecer os processos de ensino e facilitar a compreensão dos assuntos relacionados aos compostos orgânicos por meio de dois questionários, um diagnóstico e outro avaliativo. O estudo foi aplicado em uma turma do 3° ano do ensino médio em uma escola estadual do município de Itacoatiara-AM. Os softwares Laboratório virtual de química Yridium, laboratório de pesquisa e ensino de química – LAPEQ-USP e Simulations for Chemistry foram utilizados para simulação de aulas práticas envolvendo experimentos de Cromatografia e para apresentação de um laboratório de química. Após a coleta e análise dos resultados observou-se que o uso do Laboratório Virtual contribui para a motivação do estudo de química orgânica, bem como ajudou a relacionar os conceitos estudados em sala de aula com o cotidiano. O estudo também mostrou que os alunos gostariam de utilizar outros laboratórios virtuais na disciplina de química, oportunizando assim novas formas de aprender para além da sala de aula.
Palavras-chave: Software; Simulações; Ensino; Experimentos.

Resumen

Las Tecnologías de la Información y la Comunicación (TIC) están presentes en nuestro día a día y en el contexto de una pandemia se insertó bastante en el ámbito educativo. En esta aproximación entre tecnologías y enseñanza, los Laboratorios Virtuales con el uso de software educativo cobran una importancia fundamental como herramienta de ayuda y apoyo en la enseñanza de la química. Considerando la gran dificultad que muchos estudiantes encuentran en la comprensión de los contenidos de la disciplina Química Orgánica, dirigida al 3° grado de Escuela Secundaria, este trabajo tuvo como objetivo investigar cómo el uso de software en la disciplina de química puede enriquecer los procesos de enseñanza y facilitar la comprensión de temas relacionados con los compuestos orgánicos a través de dos cuestionarios, uno de diagnóstico y otro de evaluación. El estudio fue aplicado en una clase del 3º año de la Escuela Secundaria en una escuela pública de la ciudad de Itacoatiara-AM. Los softwares Laboratorio Virtual de Química Yridium, Laboratorio de Investigación y Enseñanza de Química – LAPEQ-USP y Simulaciones de Química fueron utilizados para simular clases prácticas involucrando experimentos de Cromatografía y para presentar un laboratorio de química. Luego de recolectar y analizar los resultados, se observó que el uso del Laboratorio Virtual contribuye a la motivación del estudio de la química orgánica, además de ayudar a relacionar los conceptos estudiados en el aula con la vida cotidiana. El estudio también mostró que a los estudiantes les gustaría utilizar otros laboratorios virtuales en la disciplina de química, brindando así nuevas formas de aprendizaje más allá del aula.
Palabras clave: Software; Simulaciones; Enseñanza; Experimentos.

1. Introduction

In today's chemistry classroom, there still prevails the teaching of decontextualized content, far from the students' reality and difficult for them to understand. Many teachers predominantly employ activities that favor mere memorization of formulas, which demotivates student learning of content (Melo & Santos, 2012; Pontes et al., 2008). Chemistry is par excellence an experimental science that demands observation, analysis, and integration of theory and practice. Hence, the use of experimentation in the teaching and learning process, e.g., lab experiments, classroom demonstrations, virtual simulations, videos, films, and investigations, is sine qua non to knowledge construction in this field (Brasil, 2002; Merçon, 2003).

Despite being considered a means of improving the teaching of chemistry and science by many teachers and scholars, experimental practices are seldom present in schools, due to the absence of laboratories or poor maintenance where they exist and lack of time to prepare lab classes on the part of teachers (Gonçalves, 2005; Silva, 2016). In addition, during the ongoing pandemic, social distancing measures have required most teaching activities to migrate to virtual learning environments (VLEs) as the best strategy to prevent its spread. However, virtual education poses some challenges to practical classes, essential to the understanding and application of chemistry concepts and theories because laboratories exist in designated physical spaces at educational institutions (Tulha, 2019).

In view of the difficulties found in carrying out experimental classes in general, and during a pandemic in particular, information and communication technologies (ICTs) have become a major asset to the teaching of chemistry as they enable interaction, participation, involvement, bidirectionality, and multidisciplinarity, thus placing the teacher as the facilitator in the teaching-learning process (Braga, 2001; Dionízio et al., 2019).

ICTs are technological tools that incorporate and enable extensive communication in different types of processes in several areas, especially in educational contexts, from teaching to research (Tavares et al., 2014). Among the accessible and available technological resources found in schools are televisions, computers, and software programs (Martines et al., 2018). According to Nascimento (2007), educational software programs may be classified as tutorials, exercises (questions and answers), investigations (electronic encyclopedias, etc.), simulations (models based on real-world situations), games (mathematical and logical reasoning), and open programs (presentation and text editors, etc.).

Simulations and animations are beneficial to chemistry teaching and learning in that they enable teachers to provide students with the necessary conditions and contexts to be able to learn its phenomena (Pascoin & Carvalho, 2021). Hence, a virtual lab may be considered a learning tool, since it enables simulations and computational representations of real-world phenomena and, for this reason, constitutes an alternative to a conventional lab, its equipment and materials (Maciel & Backes, 2013; Schmitt & Tarouco, 2008). Lab software allows students to navigate in a tridimensional laboratory displayed in a way that they can interact with glassware, equipment, and reagents (Amaral et al., 2011; Lucena et al., 2013).

In addition, Lucena et al. (2013) claim that experimental classes are essential practices to the chemistry teaching-learning process and that ICTs, i.e., educational software programs that simulate real-world experiments, constitute an alternative didactic resource to the teaching of this field of knowledge. In that sense, this study aimed at investigating whether and how the use of lab software programs could improve the teaching of chemistry and facilitate student understanding of topics related to organic compounds.

2. Method

This case study, an intervention research of a qualitative nature, considering that the data obtained from observation, through the application of questionnaires as a research instrument and through verbal interactions (Ludke & Andre, 2013). At first involved theory classes given by UFAM (Federal University of Amazonas) undergraduates from the following programs: Science Baccalaureate (Chemistry and Biology), Industrial Chemistry, Pharmacy (ICET – Institute of Natural Sciences and Technology), and a graduate student from the Graduate Program in Science and Technology for Amazonian Resources (PPGCTRA). Data were collected by means of two questionnaires, pre-intervention (diagnosis) and post-intervention (evaluation). Afterwards, lab practices were recorded at an ICET-UFAM research lab and at virtual laboratories.

As to the field activities, at first the authors asked the principal of a public school in Itacoatiara, AM, Brazil, to make the project public among its faculty. Later, online meetings were held with faculty teaching organic chemistry (3rd-year/final year students) about the methodology to be employed in the intervention. Then, the 3rd-year students were asked to respond to a pre-intervention questionnaire to assess their previous knowledge of the theories and concepts in question, namely, organic functions, nomenclature, intermolecular interactions, and physical properties of organic compounds. The pre-intervention questionnaire comprised 12 questions, nine of which relating to the abovementioned concepts and theories and the remaining three eliciting their opinion about alternative teaching methods employed by their teachers until then. Afterwards, Google Classroom video classes on the above topics were made available as well as lab practices conducted at UFAM and virtual laboratories, i.e., IrYdium Chemistry Lab, LAPEQ-USP (Laboratory of Research in Chemistry Teaching and Educational Technologies, University of São Paulo), and Simulations for Chemistry. A graduate student and an undergraduate student, who do research in natural products at UFAM, carried out the lab practice at ICET. They performed essential oil extraction using a Clevenger-type apparatus.

After the intervention was prepared, the project was presented in person to the participating 3rd-year students at João Valério Secondary School (Figure 1).

Figure 1 – Implementation of project at João Valério Secondary School in Itacoatiara, AM, Brazil: (A) Teacher introducing project team; (B) Virtual lab for presentation of equipment and glassware; (C) Project made public on social networks; (D) Chromatography experiment.

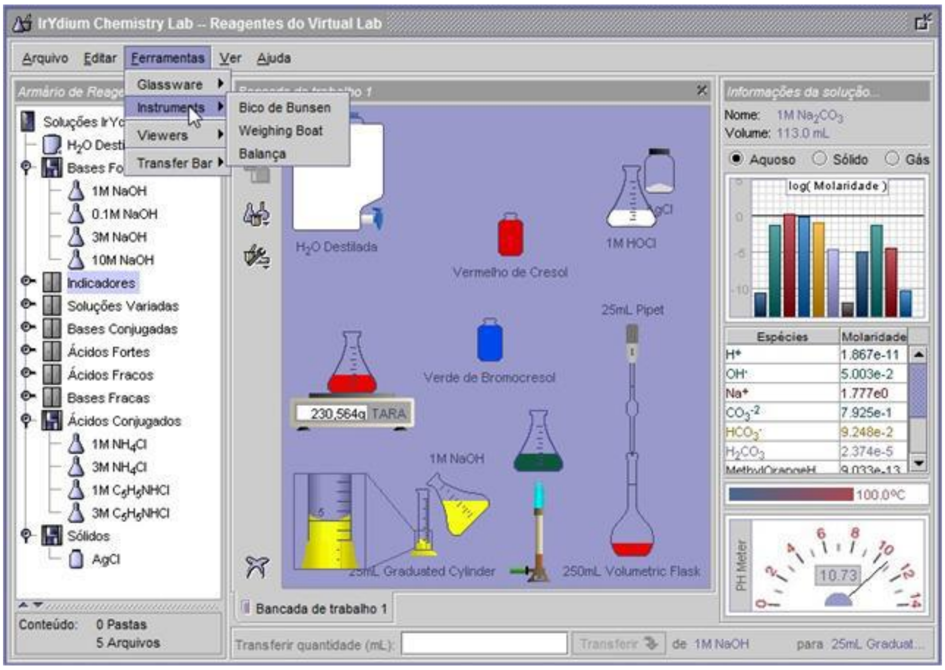
Source: Authors.

The authors organized and provided the participating school with five booklets with theories and procedures in support of the experimental classes. In addition, a post-intervention questionnaire was prepared to be responded by the participating students in order to evaluate the teaching-learning process employed in the intervention and to check whether it had improved student knowledge of the theories and concepts in question. The post-intervention questionnaire also included another question in which the participants were asked to express their opinions about the project.

As aforementioned, experimental classes were simulated by means of IrYdium Chemistry Lab, LAPEQ-USP, and Simulations for Chemistry. The IrYdium Chemistry Lab is an application initially developed in Java, but it also has an HTML5 version now. Both versions are available free of charge at www.chemcollective.org/vlab and can be used directly via a browser or installed on a computer for offline use. The IrYdium Chemistry Lab is a simulator capable of carrying out experiments at a virtual chemistry lab. It allows students to select and handle various reagents, simulating a conventional/physical lab. Interactive exercises enable students to better contextualize the chemistry content taught in class, connecting abstract concepts to real-world applications and experiments.

Figure 2 Shows the offline version of IrYdium Chemistry Lab. The area of the screen to the left of the virtual lab (center workspace) is the reagent storage cabinet.

Figure 2 – Reagent storage cabinet of IrYdium Chemistry Lab.



Source: Authors.

The center software workspace provides an area for conducting experiments, functioning as a real-world workbench. The area on the right provides multiple representations of selected solution contents, including temperature, molarity of substances, and pH (Figure 3). The HTML5 version of the software can also be accessed via a browser and, for that reason, by mobile devices.

Figure 3 – Virtual lab workbench.

Source: Authors.

The chromatography experiment was carried out at LAPEQ-USP virtual lab. This VLE is developed in FLASH and can be accessed free of charge at *http://www.lapeq.fe.usp.br/*.

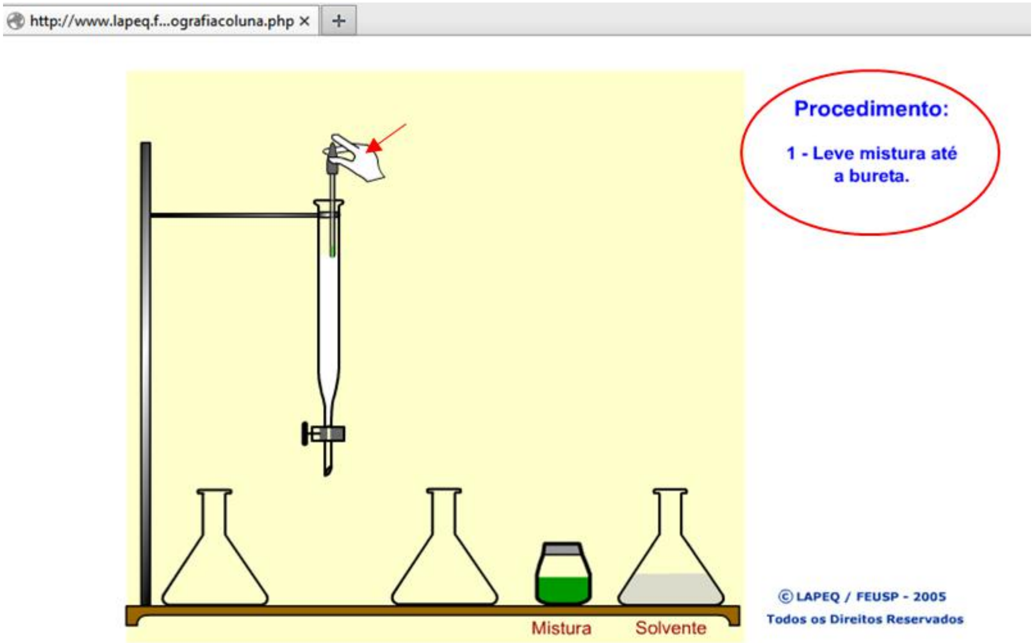
Figure 4 shows a screenshot of LAPEQ-USP virtual lab featuring hypermedia, animations, simulations, videos, a structure bank, MOODLE (virtual classroom), teaching sequences, and a repository of digital objects for teaching science and chemistry.

Figure 4 – Virtual learning environment of LAPEQ-USP.

Source: Authors.

Of the tools available at LAPEQ, an animation tool capable of simulating a chromatographic procedure (column chromatography) was used in the intervention. Although it cannot be downloaded, the entire process can be conducted offline. The experimental procedure is carried out following the animation guidelines with the aid of the computer mouse (or notebook touchpad), as shown in Figure 5. After completing a step, guidance changes automatically for starting the next step. At the end, it is possible to redo the entire experiment.

Figure 5 – Column chromatography animation. Step: 1 - Add mixture to burette. Arrow: Place where the cursor was positioned.



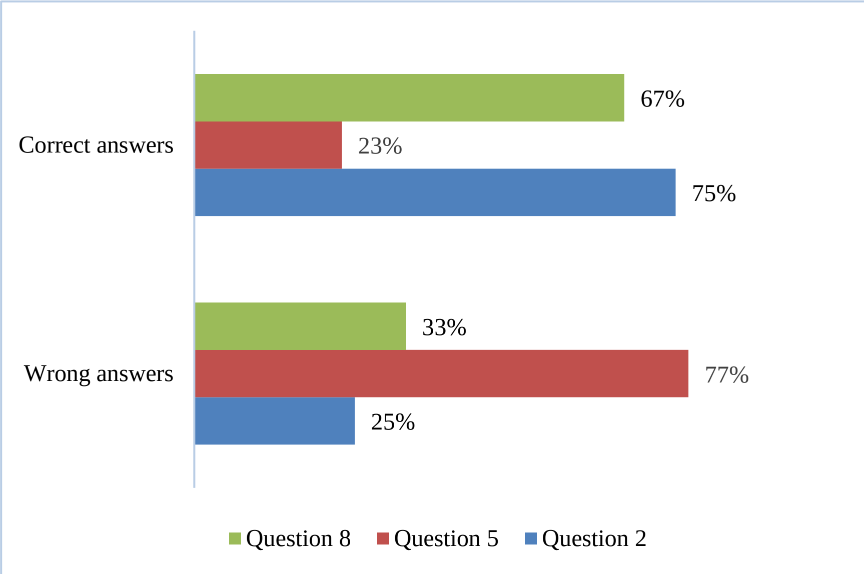
Source: Authors.

3. Results and Discussion

According to Filho et al. (2020), today's students are not committed to studying in ways that pre-Internet students were. Many students do not feel motivated to attend school; they often do so out of obligation, which makes learning difficult. The curriculum content is often seen as something to be memorized and later discarded. This lack of motivation is frequently associated with conventional classes, commonplace in schools, which do not work as effectively as they used to. Several institutions still cling to simple outdated models, in both face-to-face and distance education, based on conventional views of teaching and learning (Morán, 2015).

The pedagogical contribution of the experimental simulations was assessed by both questionnaires, applied before and after the intervention activities were carried out. Questions 1, 2, 5, and 8 of the pre-intervention questionnaire were objective questions. Q1 and Q2, about organic functions, were answered correctly by 100% and 75% of the students, respectively. However, just 23% of the participants got the question about nomenclature (Q5) right. As to Q8 (physical properties of organic compounds), 67% of correct answers were identified (Figure 6). These results indicate that while the participants had some previous knowledge of organic functions and physical properties of organic compounds, their knowledge of nomenclature and intermolecular interactions was insufficient. This was corroborated by their answers to the remaining questions in the pre-intervention questionnaire; Q4 and Q6, both about nomenclature, were answered correctly by 45% and 35% of the students, respectively. In Q7 and Q9, both about intermolecular interactions, the percentage of correct answers was 1.2%.

Figure 6 – Pre-intervention questionnaire results.



Source: Authors.

The three last questions in the pre-intervention questionnaire concerned the difficulties found by the participating students in their organic chemistry classes and what teaching-learning resources had been employed until then, as shown in Table 1.

Table 1 – Students' opinions about their chemistry course and previous use of educational games and lectures.

PRE-INTERVENTION QUESTIONS	ANSWER OPTIONS
10. Do you find this year's chemistry content interesting?	( ) Yes ( ) No
11. What is the difficulty level of the course?	( ) Easy ( ) Moderate ( ) Difficult
12. Which teaching-learning resources have been used in the teaching of chemistry so far?	( ) Experiments ( ) Films/Music ( ) Educational games ( ) Discussions

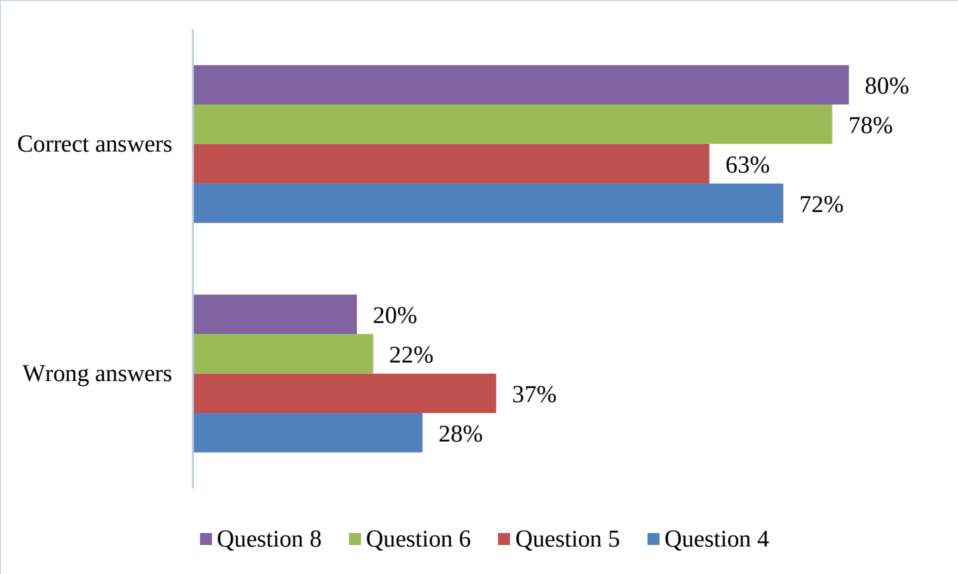
Source: Authors.

Accordingly, when asked whether they considered the organic chemistry content interesting, almost 100% of the students agreed that it was interesting. However, 90% of the respondents reported moderate difficulty in learning the curriculum content in question. As to the teaching-learning resources that they had been exposed to in their chemistry classroom until then, only 43% of the students reported that they had had lab classes in secondary school.

By means of the post-intervention questionnaire, i.e., after the aforementioned virtual lab activities, two dimensions were analyzed: the students' perceptions concerning their learning and their assessment of the VLE tools employed in the project.

Thirteen out of the 30 participating students responded to all the post-intervention questions. Figure 7 shows that the intervention promoted student learning of the chemistry content in question. It is worth noting that all the respondents gave right answers to Q1, Q2, and Q3 and the quantity of correct answers to Q4, Q5, Q6, and Q8 increased significantly.

Figure 7 – Post-intervention questionnaire results.



Source: Authors.

These results indicate that lab classes carried out online by means of teaching and educational software that simulates a chemistry lab were capable of promoting the students' leaning in a proper, albeit simulated, laboratory context, by inciting them to navigate and engage with the curriculum content in question. Experimental activities can serve as a powerful stimulus, impulse and incentive to awakening or maintain student interest in the contents worked in the classroom and consequently enhance learning (Gonçalves & Goi, 2020; Laburú, 2006;). These, for the most part, believe that science experiments increase the efficiency of learning (Faria et al., 2020). White (1996) also claims that these activities predispose students to construct new knowledge, acting on the emotional segment of their mental structures. Hence, it is possible to affirm that the use of virtual laboratory activities has met the project objective and constitutes a motivating tool for learning chemistry. In this study, it was possible to observe a positive trend in the 'perception of learning' dimension, which aimed at assessing, from the participants' perspective, whether the use of virtual labs had promoted and improved their understanding of concepts and theories, thereby contributing to the teaching-learning process.

The last three questions in the post-intervention questionnaire concerned the participating students' opinions on the project and its implementation and on the insertion of practical classes in the teaching of chemistry. Their answers indicate that the project was well received. Despite the difficulties posed by pandemic —deriving from the socioeconomic context, online teaching, and the use of teaching tools previously unfamiliar to the students — it appears that associating experimentation with chemistry curriculum content by means of ICTs can contribute to student engagement and, as a result, learning.

4. Conclusion

Information and communication technologies (ICTs) have shown to be strategic alternatives to the teaching of chemistry. Simulators, which allow students to engage in practical chemistry, albeit virtually, can make knowledge construction more enjoyable and efficient. The results from this study indicate that the use of simulated experiments in organic chemistry classes leads students to experience novel ways of teaching and learning, different from those usually found in conventional classrooms. It can contribute to student understanding of concepts and theories previously taught in lectures, in addition to promoting student autonomy regarding lab practices. This approach is of great importance to the chemistry classroom, especially in times of uncertainty due to constant school shutdowns. In addition, the use of ICTs provides students with another tool to learn and incorporate organic chemistry concepts and applications.

Through this work, it was observed that the use of simulators can be used in more contents with the objective of contextualizing all the theoretical subjects of the organic chemistry discipline. Therefore, for the next works, it is expected to expand the virtual experiments and quantify the promotion of student learning.

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