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Challenges in Teaching Organic Chemistry Remotely

Carina I. C. Crucho,* João Avó, Ana M. Diniz, and Mário J. S. Gomes

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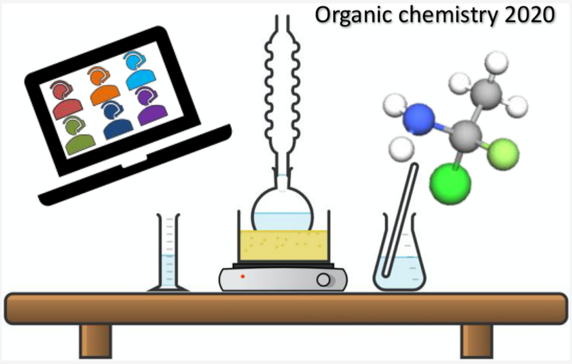
ABSTRACT: The coronavirus disease (COVID-19) pandemic has changed not only people's daily lives but also the education system. The rise of e-learning all across the world has challenged both students and teachers to adapt to digital technologies and a novel learning experience on both sides. As if COVID-19 was not enough, many students were facing the alien territory of organic chemistry for the first time. There is no denying that organic chemistry is a tough subject, and several students may also have preconceived misconceptions. In addition, organic chemistry can be challenging to teach remotely. It is very abstract in nature; it involves many concepts, and the teacher typically uses molecular models of one kind or another to depict molecules in three dimensions. Nonetheless, challenges provide an opportunity to implement new strategies to increase students' interest, motivation, and understanding. However, most educators only had a few days to put everything they do in class onto an online platform. In this study, we evaluated the effect of these changes in the teaching and learning of organic chemistry at a first year undergraduate level. Our results show that student success depends on the digital resources used for the different subjects. Students that received weekly quizzes performed better than those who did not, and a positive correlation exists between quiz score and final exam marks. Based on the students' feedback, the implementation of quizzes was a successful didactic tool that helped them review the topics. In addition, the incorporation of open-access web-based tools led to a dynamic online classroom experience.



KEYWORDS: *General Public, Continuing Education, Organic Chemistry, Professional Development, Distance Learning, Stereochemistry*

The year 2020 will always be marked by the global pandemic caused by a coronavirus (SARS-CoV-2) but also by how forced remote learning changed the teaching and learning landscape.[1] Perhaps the pandemic only hastened what was expected for a long time: complete integration of technology into education. As a matter of fact, Exploring Everyday Chemistry, a massive open online course (MOOC), was successfully used as a digital educational tool between 2017 and 2019 to attract high school students to pursue a chemistry-related degree at a university.[2] However, the pedagogy is not the same as teachers use in the classroom and cannot be directly transferred for a remote teaching format. Thus, planning and designing an online program to use during forced confinement is time demanding and requires support and technological facilities. The required resources depend on the specific course, and organic chemistry (OChem) is particularly demanding, as it has always been considered a difficult topic and a challenge to teach among undergraduate students.[3] The key to mastering OChem is through extensive practice, and converting conventional methods to e-learning must guarantee that this part of the curriculum is not neglected. Herein, we describe our work in converting our OChem course into a remote teaching format, which included the use of open-source online tools and the design of several quizzes to keep taught concepts up to date and monitor students' progress. We also evaluated the effects of using additional visual support during online lessons and making it accessible to students asynchronously, and student performance and attendance were monitored throughout the isolation period. The present study also attempted to determine whether administering weekly quizzes during the pandemic period results in better performance on final scores.

■ LEARNING ENVIRONMENT

This study was conducted in Lisbon School of Health Technology (ESTeSL), a public higher education school, integrated in the Polytechnic Institute of Lisbon (IPL), Portugal. The polytechnic schools can be compared to the community colleges in the Unites States, offering a more

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practical training and are profession-oriented. ESTeSL offers Degree Courses, adapted to the Bologna Process, and Master Programmes in the area of Health Technologies. OChem was taught to Environmental Health students as part of a 5 credit module (ECTS). Students enroll in this course during their second semester, after having studied Applied Chemistry in the previous one. The OChem course consists of 3 h/week of theoretical class split into two blocks of 1.5 h. Theoretical—practical lessons consist of 1 h/week for 5 weeks, where students do not have access to computers. These are followed by laboratory periods, lasting 2 h, once every 2 weeks, for the acquisition of laboratory technical skills. During the pandemic, in ESTeSL, the application of both synchronous and asynchronous moments was encouraged, and in the OChem course, it was immediately and effectively implemented. For the synchronous moments, the classes were conducted on the Zoom platform, as it allows both live video communication and online chat. For the asynchronous periods, e-mail and the learning platform Moodle were used as they are globally supported and allow teachers and students to exchange information.

Following the top recommendations, the synchronous classes took place using the same schedule that prevailed before the confinement, but there was some flexibility to adjust the length of synchronous lessons to best fit the teaching—learning process. In the OChem course, it was decided to keep the duration of synchronous theoretical classes similar to the duration of face-to-face classes, while the duration of the theoretical—practical classes was increased to 2 h/week.

The students' punctuality was better than in face-to-face teaching, most likely because they did not have the social factor as a distracting element. Although remote lessons were not mandatory, as per institutional regulations, student attendance was initially similar to that which is usually seen in face-to-face lectures but decreased gradually overtime.

ENGAGING STUDENTS IN LEARNING ACTIVITIES

Support Software and Tools

Perhaps the most demanding aspect of teaching OChem remotely is related to stereochemistry. Visualizing molecules in 3D and interconverting between different projections is difficult, but it is an essential skill for OChem students. It has been documented that students have difficulties in 3D visualization,[4] but the good news is that it can be trained. Educators have gone the extra mile to help students overcome the perils of stereochemistry by developing different teaching strategies, including educational games.[5] In the classroom, in order to help the students visualize and conceptualize stereochemistry principles, educators usually use molecular models, such as ball-and-stick.[6] Students are encouraged to build their own models with plasticine to represent atoms as spheres and cotton buds or toothpicks to make the atom connections.[7] However, misconceptions can arise because, by building the models by themselves, bond angles are often overlooked. Although using molecular models in the classroom is usually a fun and engaging activity, at home, only the teacher is allowed to play. Therefore, during the remote classes, it is not easy to bridge the gap as effectively as in the classroom. A teacher's perspective on a particular orientation of a molecule in face-to-face learning can be easily demonstrated by turning the back to the students, so everyone is facing the same direction, increasing student spatial ability. With remote learning, however, perceiving the location of objects and their relationships with the observer is not an effective strategy. Software is very helpful in teaching stereochemistry, and it could supplement conventional teaching methods.[8] Moreover, it is known that virtual models are just as effective as physical ones.[9] To achieve this, MolView, an open-source, intuitive web application, was introduced to the students. MolView can be used to draw organic molecules and convert the structure to 3D (Figure 1).

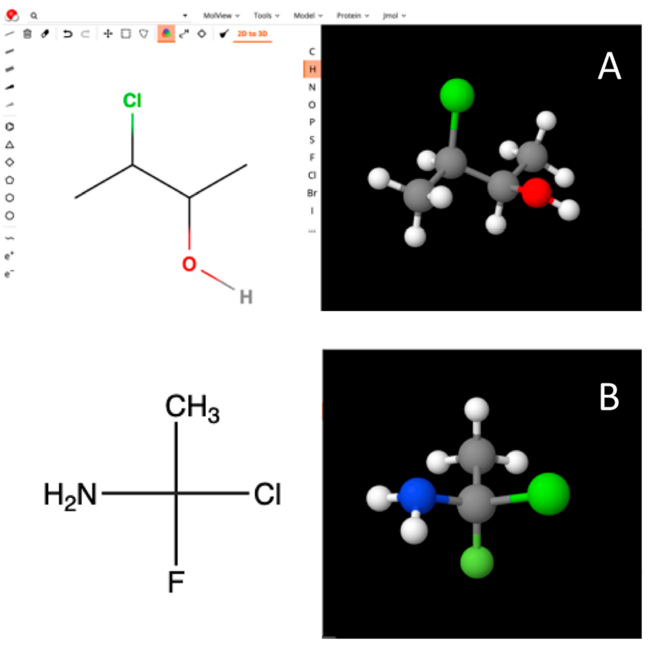

Figure 1. MolView visualization tool. Molecular model for 3-chlorobutan-2-ol (A) and 1-chloro-1-fluoroethan-1-amine depicted in a Fischer projection (B).

Students can rotate and zoom in or out these virtual models and change the perspective as they would be able to do with a physical model. In addition, it is also very useful to explain the true 3D information present in a Fischer projection, something that students find difficult to perceive (Figure 1b).

To draw structures, Chemdraw, a leading chemistry molecule drawing software usually not accessible to students, can also be used. Through screen sharing on an online platform such as Zoom, students are invited to remotely manipulate images on the teachers' computer. Initially, many students will hesitate at first, but they will accept the challenge. This activity helps students to better understand and follow the teacher's reasoning, to exercise simultaneously and to visualize the bulkiness of a molecule. However, this type of class is very time-consuming by demanding a lot of student—teacher interaction, and the class time will probably be insufficient to solve all of the planned exercises. Another approach is to share a PPT presentation with the students, so they can view the presentation and then listen to the resolution simultaneously. The students are encouraged to use the annotation tools on the shared PPT to solve the problems, and then the resolution is provided. One particular disadvantage of this approach is that the PPT material may be misunderstood without the real-time interaction.

Launching a Quiz

Teachers usually seek immediate student feedback as a vital part of the learning process. During a forced isolation period, remote teaching poses a significant hindrance to this process, and new strategies are needed. To make lessons more interactive and engaging, implementing a quiz is a good alternative, aiding students' practice and review of concepts already covered, while helping educators monitor and assess learning.[10] Several studies have shown the benefits of quizzes in increasing student's attendance and helping them to retain the material for a longer period of time.[11,12] In addition, results indicated that students with weekly quizzes performed better on the final examination.[12] On the other hand, too frequent testing could promote anxiety and hinder learning.[12] Thus, the quizzes were designed to contain a set of 10 multiple choice questions and 2 min per question to answer and were performed on a weekly basis at the start of each practical class. This also helped the students to focus right away and prepare them to learn. The questions were presented on screen through a PPT presentation, and the students could only see one question at a time. The students were asked to do the quizzes on their own and send their answers privately to the educator at the end of the quiz. After that, feedback on both correct/incorrect responses was provided to the students for each question. Two criteria were addressed: (i) by institutional regulations, students were not officially evaluated; (ii) the questions should cover the content seen in the prior theoretical classes. Each quiz was built according with the sequence shown in Table 1.

Table 1. Distribution of Topics Covered in Quizzes

quiz	topics
1	structure and bonding; nomenclature; stereochemistry
2	structure and bonding; nomenclature; stereochemistry; alkanes/haloalkanes
3	structure and bonding; nomenclature; stereochemistry; alkanes/haloalkanes
4	structure and bonding; nomenclature; stereochemistry; alkanes/haloalkanes; alkenes and alkynes
5	structure and bonding; nomenclature; stereochemistry; alkanes/haloalkanes; alkenes and alkynes; alcohols, aldehydes and ketones
6	structure and bonding; nomenclature; stereochemistry; alkanes/haloalkanes; alkenes and alkynes; alcohols, aldehydes and ketones
7	structure and bonding; nomenclature; stereochemistry; alkanes/haloalkanes; alkenes and alkynes; alcohols, aldehydes and ketones; carboxylic acids

Each question had only one correct answer and two or three distractors. As OChem builds new topics from old ones, questions may test a knowledge of more than one topic. The majority of students (~70%) enrolled in practical lessons undertook the quizzes even though the quiz score did not contribute to the final grade. They were probably motivated by the possibility to pursue additional practice exercises. Examples of questions (translated from Portuguese by the authors) are presented in Figure 2. The OChem practical classes usually provide a "hands-on" environment, to connect the theoretical concepts with a laboratory experience. However, during a global health emergency, teaching laboratories are shut down. Experimental laboratory setup could be introduced for visualization in quiz questions. This can be done with a free online editor for drawing science lab diagrams and school experiments such as Chemix.[13] Alternatively, a virtual chemistry laboratory also aims to facilitate the science teaching process with realistic simulations.[14]

EVALUATING THE IMPACT

In order to assess the efficacy of the implemented remote teaching methodologies, we addressed the following questions:

(1) Did changing to remote teaching affect learning negatively?
(2) How did different remote teaching methods influence learning of different subjects?
(3) How did the remote format of practical classes affect engagement?

To answer these questions, the following parameters were analyzed: student performance in quizzes, class attendance over nine theoretical–practical lectures, and the final exam scores. The study population was composed by 35 first-year students and 25 second- and third-year students, with ages between 18 and 22 years old and 3:1 female-to-male ratio.

Figure 3 depicts the data collected during theoretical–practical classes, attended mainly by first-year students. It is shown that the majority of quizzes had an approval rate above 50% and increased over time (Figure 3a). With a quiz in the beginning of each remote class, students faced a pseudoevaluation that required the application of subjects taught in previous classes. This approach helps students retain and practice these subjects throughout the semester, which would not otherwise be revisited before the final exam. With an overall positive score in quiz answers for all of these subjects, these results show that the adopted pedagogy did not have a negative impact in learning (question 1). The two adopted models of theoretical–practical lectures used during the isolation period, that is, visual support with PPT slides (with slides) versus on-the-fly resolution of problems using a chemical drawing software (without slides), were also compared (question 2). It is shown in Figure 3b that there is no significant difference in overall quiz approval rate, with both methods reaching similar values at a later stage of the semester. The only significant difference between both methods is related with organic reactions, for which students with PPT-supported lectures scored higher (Figure 3c). These results suggest that a more interactive approach is adequate when subjects requiring abstract thinking, such as stereochemistry, are being covered, whereas slides with presolved problems are more effective in covering a large amount of information.

Due to institutional regulations, remote classes were not mandatory. The effect of this measure became evident for theoretical–practical classes when student attendance is observed over time (Figure 3d), which decreases steadily during the isolation period. This indicates that student engagement waned as quarantine boredom started to set in and more demanding subjects, such as judging trends in reactivity and predicting chemical changes,[15] were introduced. However, despite the nonmandatory regime, the semester ended with a remote attendance of ~70%, which demonstrates that the adopted teaching methods were sufficiently engaging (question 3).

Finally, looking at the final exam scores, it was possible to further assess the effects of launching quizzes in student learning. While attending quizzes or not did not affect the final exam approval rate, students attending quizzes score

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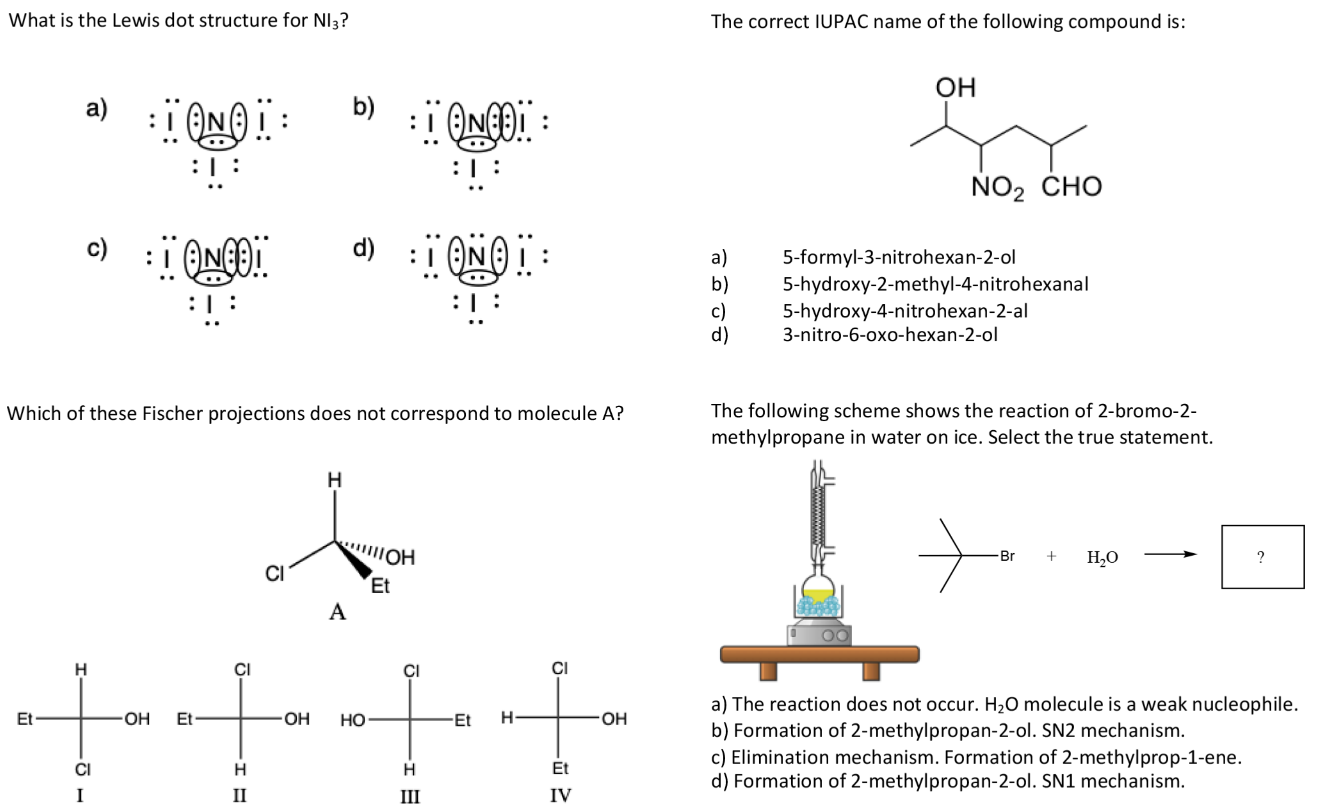

Figure 2. Examples of multiple-choice quiz-type questions covering topics such as Lewis structures, IUPAC nomenclature, stereochemistry, and reactions (created with Chemix[13]).

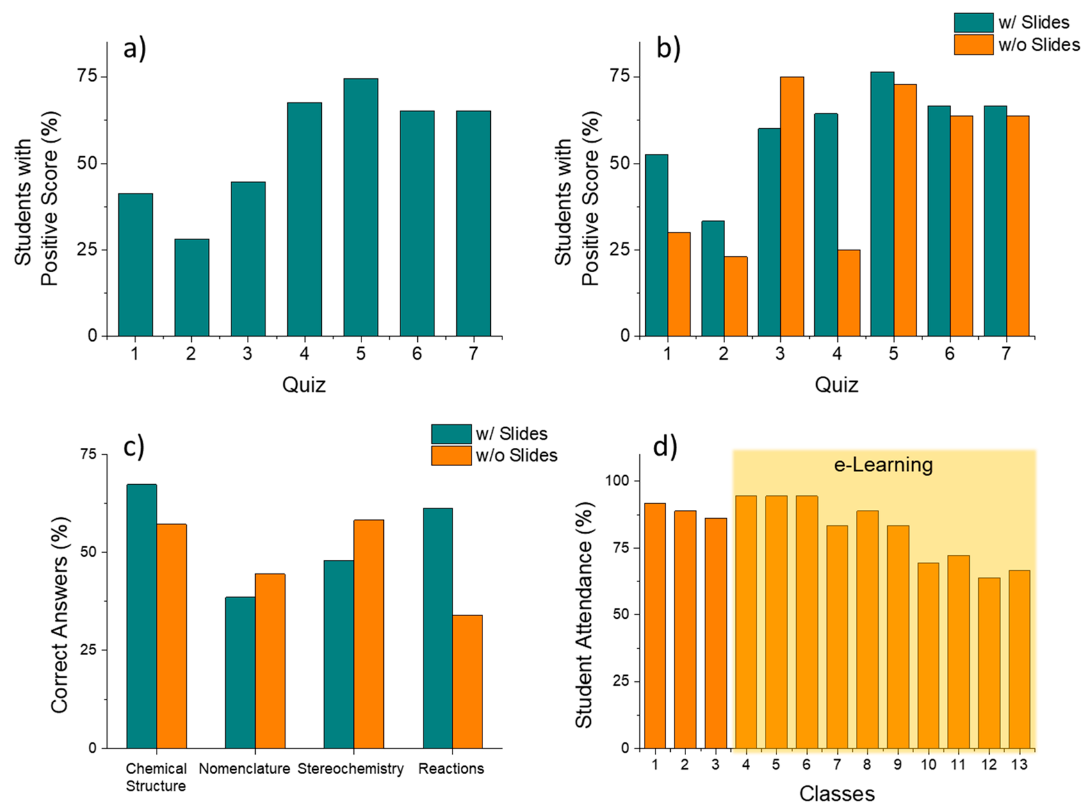

Figure 3. (a) Percentage of students with positive scores on quizzes. (b) Percentage of students with positive scores according to the methodology applied in e-learning. (c) Percentage of correct quiz answers per subject. (d) Statistics for attendance.

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significantly higher than those who did not, with the final score average increasing from 8 to 11 out of 20 (Table 2). We believe this arises from both a higher engagement of these students toward the course and to an increase in preparedness due to constant practice in remote classes. In addition, when looking at both quiz score average and final exam score, a positive correlation becomes evident (Pearson's r = 0.7, R^2 = 0.48, N = 27) (Figure 4).

Table 2. Final Exam Results

	final exam approval rate (%)	final exam score average (out of 20)
quiz	54	11
no quiz	54	8

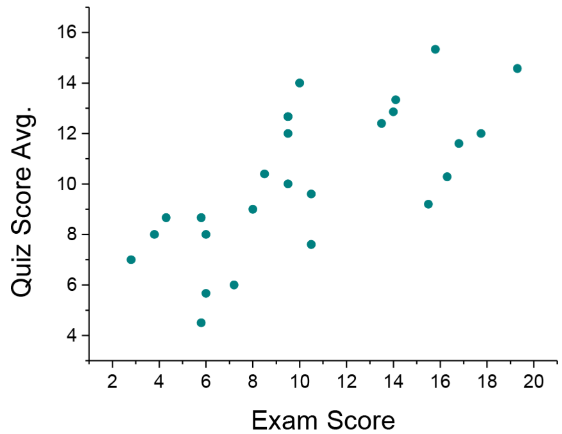

Figure 4. Scatter plot evidencing the correlation of final exam score and quiz score average for each student.

STUDENTS' OPINIONS

At the end of the online classes, students were questioned on the pedagogical online tools implemented during the semester. The survey containing eight items was answered on a volunteer basis and anonymously and was approved by the ethics committee. Not all students provided answers to these questions. Examples of items (translated from Portuguese by the authors) are presented below:

- Distance learning was a challenge for everyone, students and teachers. As a student, did you notice any benefits of distance learning?
- What is your opinion on the implementation of quizzes as a tool for monitoring students' knowledge?
- Are there any methodologies that you would like your teachers to maintain even after it is safe to resume classroom teaching?

Regarding the benefits of e-learning, 58% of students answered positively, mainly for not having to commute to campus and getting more class time dedicated to the solution of exercises. However, a smaller percentage of the students (16%) also complained that online classes were more exhausting, suggesting a reduction of class time or a small break. We also asked students if they appreciated the quizzes, and 95% of them answered positively. In addition, students said that the online quizzes reduced their stress levels for the online exam evaluation.

Some students manifested their opinion with statements such as the following:

"Great tool for the application of the knowledge acquired in the theoretical classes given the high number of subjects that is taught. It also allows you to practice exercises on previous topics." (regarding quizzes)

"In my opinion, the subjects should be reduced, and the practical classroom sessions should be used to solve exercises for a longer period of the semester than what is stipulated, since I find it very difficult to understand the subject without solving them with support."

CONCLUSIONS AND FUTURE DIRECTIONS

There is always a resistance to new methodologies, until some event forces us to change. The pandemic will pass into history, and what happens next is an open question, but online education will eventually become an integral part of our educational system. Therefore, we need to look for ways to further improve it by studying the behaviors and results of our students in this atypical semester. Students' mental health is also a concern because they need to learn the new dynamics of remote learning and learn how to manage their schedule. It was noted that online quizzing had a significant impact on student engagement. In addition, the results revealed that online quizzing lead to higher scores on the final examination. These findings might be valuable for educators who wish to conduct regular testing through quizzes to motivate students to attend remote classes and keep them motivated to learn. We still do not know if this was a once-in-a-lifetime occurrence, but as indicated in this study, online quizzes might be considered an effective and satisfactory methodology for teaching OChem. In addition, several online tools helped to translate the OChem course into its remote version.

AUTHOR INFORMATION

Corresponding Author

Carina I. C. Crucho − *IBB-Institute for Bioengineering and Biosciences, Instituto Superior Técnico, Universidade de Lisboa, 1049-001 Lisbon, Portugal; Health Technology College of Lisbon (ESTeSL) - Polytechnic Institute of Lisbon, 1990-096 Lisbon, Portugal;* orcid.org/0000-0002-6361-2800; Email: carina.crucho@tecnico.ulisboa.pt

Authors

João Avó − *IBB-Institute for Bioengineering and Biosciences, Instituto Superior Técnico, Universidade de Lisboa, 1049-001 Lisbon, Portugal; Health Technology College of Lisbon (ESTeSL) - Polytechnic Institute of Lisbon, 1990-096 Lisbon, Portugal;* orcid.org/0000-0002-3380-748X

Ana M. Diniz − *IBB-Institute for Bioengineering and Biosciences, Instituto Superior Técnico, Universidade de Lisboa, 1049-001 Lisbon, Portugal; Health Technology College of Lisbon (ESTeSL) - Polytechnic Institute of Lisbon, 1990-096 Lisbon, Portugal;* orcid.org/0000-0003-3157-6937

Mário J. S. Gomes − *Health Technology College of Lisbon (ESTeSL) - Polytechnic Institute of Lisbon, 1990-096 Lisbon, Portugal; H&TRC (Health and Technology Research Center) - ESTeSL/IPL, 1990-096 Lisbon, Portugal;* orcid.org/0000-0003-2920-0201

Complete contact information is available at: https://pubs.acs.org/10.1021/acs.jchemed.0c00693

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Notes

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