Chapter 23
Towards Digital Laboratories:
Transition Challenges of an Undergraduate Chemistry Laboratory Curricula

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ABSTRACT

This chapter discusses key elements when devising a transition from traditional laboratory classes towards a digital platform. First, an overview of the types of online and digital chemistry laboratory teaching methods is described. Then it is analyzed a specific case of an abrupt transition of curricula of a practical chemistry undergraduate class. The assessment will be argued with a series of tasks that aim to identify challenges using a real-life laboratory transition. This will be done by outlining the major influences of teacher's transition outtakes.

INTRODUCTION

The global pandemic of SARS-CoV-2, coronavirus outbreak in 2020, instigated several restrictions to academic activities (Allo, 2020). In the early stages of the pandemic, between March and May of 2020, public health services guidelines advised many European Universities to shut down all activities, as a state-wide quarantine were established. As a result, all in-person activities were reduced, cancelling curricular activities and suspending regular events for the remaining academic period. By early November 2020 into 2021, a second wave of increased cases have already virtually caused all European Universities to have experienced some form of lockdown. To address the situation, the Offices of Public Education and Higher Institutions, sanctioned Universities to adopt contingencies as to shift education to an online base[1]. Promptly, university students stopped their curricular activities, cancelling all in-person classes until further notice[2]. Therefore, higher education activities were encouraged to materialize their activities online. Although many Universities have already adopted various types of resources and activities

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over the internet, nothing at this scale was properly implemented or even tested. The goal was to assure online classes for all University students, and performing evaluation activities, either in theoretical or practical courses. However, despite the compulsory situation we all face, can an online class mark the same performance as a traditional class?

The idea of having dematerialized class-outputs is not new to the academic world. They can virtually reach any university student anywhere, enabling them to access class-content outside the classroom. (Baturai, 2015; Lee, 2018). Major resources for these outputs comprise video explanatory lectures, evaluation forms and other curricular assignments. This provides resourceful insights on student monitoring and development, giving teachers novel ways to approach many students per class (Daniel, 2015; Yuan, 2013). Let us not forget that this is all possible through the digital accomplishments of the internet, such an important source of knowledge for the students. It is easy to conceive the idea of having exposition and theoretical classes being taught online as if they were an online course, especially when there is no other alternative to an in-person lecture.

But what about practical classes? They are more than a theoretical approach to practical concept. Students have those classes because they need to get in touch and materialize previously lectured concepts. In a science class, sometimes it is often challenging to teach how to work with an equipment or perform certain laboratory tasks, without an "hands-on" activity to ease the gap. Recognizably, significant parts of information that students keep during a laboratory class are given while they perform the practical activity. As this level, especially with young university students, the void left by the absence of "hands-on" activities must not be ignored when assessing information retention. But that poses a challenge. How do we change to virtual based learning, without losing all the positive aspects of in-person laboratory activities?

So, a question must be asked: is it possible to teach a laboratory class online, while maintaining the objectives of teaching the practical aspects of a science subject? If universities need to change their classes to an all-online base, should the programs be changed and ease the practical component? What skills need to be assured, even with undertaking these classes online? And better yet, what skills does the teacher require having to successfully engage science students in an online practical class?

The presented chapter contains two sections. It will start with an outline of the current state of digital and online chemistry classes. The focus will be on what types of classes are being introduced to digital mediums and student/teacher perception of them. In a second stance, we introduce a case study of a University chemistry practical course that abruptly suspended its activities because of the March 2020 COVID-19 lockdown. An assessment for determining the key changes made to transform a traditional laboratory class into a digital online class is introduced. And finally, we present the results of the assessment made towards the teachers involved in this activity, highlighting the key aspects on the shift towards a digital transition of the class. Thusly our goals with this chapter handbook are as follows:

1. Current state of digital and online chemistry classes.
2. Case study from a chemistry course that suspended activities.
3. Assessment of shift to online teaching.

ONLINE CHEMISTRY CLASSES

An Overview

One can define online teaching as nothing more that eliminating the contingency of the student and teacher in the same room (McIssac, 1996). It is easy to understand that with the current proliferation of digital content vehicles, either text or video, it makes viable to students to be immersed in different educational contexts. Moore and Kersley present a definition more suited to this approach (Moore, 2010), by recognizing this to be a learning tool, allowing the participants to communicate in different physical space through technological enhancements. However, Finch and Jacobs amass this notion with the specificity of "a form of teaching" in which the interlocutors are not in the same geographical site, for a temporary timeframe (Finch, 2012). And it makes sense, given the structural foundations of traditional university and early educational levels. But even more traditionalist scholars must recognize the fundamental change in the conceptualization of academic courses (Sun, 2016).

Any attempt to shift a chemistry university course to an online base, should prioritize the development of the laboratory classes. In the literature, we can find previous attempts to transpose specific elements of in-person laboratory classes to outside of their campus (Casanova, 2006). These options include the use of laboratory kits in which students perform experiments from their household, attending online demonstrations, or perform virtual experiments in a digital environment (Phipps, 2013, Dalgarno, 2009). As we previously mentioned, online lectures can easily be categorized as an extension of theoretical classes. On the other hand, enabling students to perform some kind of manipulation, either in a laboratory-kit or a software, can ease a digital transition of a laboratory class (Tatli, 2013).

Taking an example of virtual experiments on a digital platform, it raises an opportunity of a simulation where students can conduct their experiments by themselves, with or without the "digital" presence of a teacher. This outing can add some perks such as multiple cost-free replications of the activity, making it easier the eventual manipulation of dangerous chemicals in a "risk-free" environment (Boschmann, 2003).

Digital experiments can also come in a form of "digital demonstrations". In this sense, teachers can broadcast the experiments, live or pre-recorded, as the students assist a representation of the techniques they are aimed to achieve.

Online Chemistry Learning

Teaching itself cannot be simply an end to a purpose of completing a curriculum. It provides means and tools to a student. Tools that cannot be completely in the shape of a pass or fail grade. They harness an opportunity to instruct future generations, beyond the traditional member who can afford high education (Sun, 2016; Moore, 2010).

In every academic curriculum concerning chemistry education, practical laboratory experiments are always part (in some form) of their syllabus. The "hands-on" approach given to chemistry students allows them to have a consistent contact and manipulation of substances and materials (Bransford, 2000). Laboratory skills are taught practically, as students learn how to acquire, treat and report experimental data, working with specific equipment and techniques, as they amass a scientific consciousness to model their critical thinking by the scientific method (Dikmenli, 2007; Woodfield, 2005). Also, practical classes are an opportunity for students to cement concepts presented in the theoretical lectures. In the particular case of chemistry subjects, students often report how practical classes are key in their overall scientific comprehension, as teachers highlight their better learning outcomes.

In contrast to other disciplines, chemistry requires ultimately a writing component. It is impossible to conceive the explanation of chemical processes and techniques without the specific chemistry language, like its symbols and equations. And the same can be applied specifically to chemistry laboratory teaching: it demands a participation component form the student, that simply cannot be achieved without some form of interaction between the user and the instrument.

But how do we blend online education with laboratory classes? We have seen the importance and positive dynamics of online-based content, mainly attempting to substitute traditional lectures. Can the same be said about online-laboratory classes?

To be engaging, such a blended format would require a more distinctive approach than traditional lectures. For example, virtual laboratory experiments could be a great asset when students prepare for their "hands-on" activity (Conway-Klaassen, 2012). They can simulate their actions online, getting familiarized with the procedures they must complete, as to attain an optimal performance in the classroom. Also, they can retry and practice as much as they want, without having to work in the actual laboratory, therefore being cost saving.

Online laboratory experiences in chemistry can range from multiple subjects and themes. The most commonly used could be a simple video tutorial on the steps to be done in the science experiment. Coped with supplementary literature on specific key topics, this can be a valuable tool to students to prepare prior to the practical experiments (Merchant, 2012). Also, software mathematical simulation that allows students to manipulate parameters of a specific experiment (Welsch, 2015). This is mostly done in practical approaches done in Computational and Quantum Chemistry.

Remote and Virtual Chemistry Teaching

When addressing digital transition of practical or experimental class activities, one may encounter novel concepts for laboratories. Mainly, the literature emphasizes either remote or virtual (Harms, 2000). Although the terms seem to overlap their meanings, they have differences that highlight specific needs for an off-campus laboratory teaching. While remote laboratories address the contingence of executing experiments on different physical spaces, virtual laboratories define the use of computers and digital means (either outside or inside the campus).

Remote laboratories have actually gained scholastic importance as it enables students to control the experiment by interfacing digitally with the instruments that are, for instance, in the actual laboratory. Basically, the student can perform certain steps embedded in the protocol, executing the experiment outside the laboratory. This can be done in executing tasks like changing apparatus parameters, operating mechanical devices or making manual sampling (Dostal, 2015). As the experiment occurs in a different location from where the student is, it enables performing important empirical actions such as data collecting and reaction performance. Although we think about this as a complement to presential courses, remote laboratory classes can help mitigate the contingencies of having to relinquish on-campus teaching.

If we look on the reported benefits of performing laboratory activities remotely to an existing "hands-on" laboratory class, we find several topics that are pivotal to digital class transition (Dostal, 2015):

- Students can interact with experiments even being physically apart;
- Some time-consuming steps (like sampling or data collecting), can be done anytime, anywhere;

- For security reasons, it can be helpful to inexperienced students;
- Familiarization with procedures, before using the remote aided devices.

The same exercise can be done for experimental virtual laboratories. Since in this modality there is no mechanical or digitally controlled element involved (Dostal, 2015), all laboratory activity is done in a virtual/digital medium, as the experiment unfolds interactively. Some depicted benefits include the ability of students being able to change variables and experiment conditions, while collecting the data and information to complete their task. Although challenging and descriptive, there is no external interaction in this undertaking. The experiment is programmed much like a sequence of steps that the student must complete, achieving their goal. This can come in handy when teaching young students basic laboratory requirements, so as they can be learned from a trivial trial-and-error strategy.

Lockdown Takeaways on Remote and Virtual Teaching

From this list, it is easy to point out strategies that can include these benefits when there is a need to change from traditional laboratory classes to a digital setting. However, especially with remote laboratory strategies, this digital transition is only partial. We can easily make students interact with the laboratories outside campus, but the instruments and their operators need to be present in the laboratory. In a lockdown scenario, with University's closed, students and teachers cannot access any apparatus. Especially if the situation is compulsory, there is no time to even design or adjust the syllabus to roll out all the experiments that seem inoperative due to the lockdown.

In the case of a global health crisis, like the 2020 coronavirus pandemic, an all-lockdown instruction would have to resume all educational activities outside the campus. With students and teachers confined to their homes, all the educational effort is to be made remotely. Thusly, if the change is abruptly made, there is no time to make necessary preparations to transfer laboratory apparatus towards a defined safe environment.

Unprepared as anyone can be, we can grasp some guidelines on remote and virtual chemistry teaching when considering a full digital laboratory transition. Combining the remarks presented above, the ideal form of tackling a hasty transition, is an amalgamation of remote with virtual teaching. The benefits of having students to remotely manipulate the experiments, must be embedded within a virtual interface, simulating the experiment without having to interact with a physical device or apparatus. As we have seen, this is much easier in some chemistry subjects, so the need to design and emulate virtual experiments towards other topics in essential. As of today, there are some works on emulating experimental topics, but almost all of them fall in the category of demonstrations, not coping an essential part of simulation and interesting, that the remote could give.

CHALLENGES ON REMOTE LABORATORY CLASSES

This section aims to address the educational challenges of a specific on-campus hasty laboratory class migration to a digital stance. COVID-19 pandemic struck the academia swiftly, without rising a preventive preparation time span to address the logistical issues of having to teach laboratory classes from home. We will discuss on the challenges that instructors faced when establishing this shift, focussing the inequities raised by the process.

We present a case study of a Portuguese University chemistry course that moved to digital activities because of the COVID-19 pandemic. This was a second-year Physical Chemistry course for undergraduate Chemistry students at the University of Porto. Three classes of 14 students were expected to be taught four practical hours per week, during the second semester of the 2019/2020 term (from February to June 2020). These classes were all taught in an on-campus laboratory, and three teachers handled their ministration. During the semester, students are required to perform several pre-planned laboratory experiments and discuss their results with their peers and teachers.

Teacher Evaluation on Digital Transition of Laboratory Classes During COVID-19

Starting from March 2020, when the Portuguese government issued a general lockdown, these classes migrated to an online basis. The schedule was maintained, but the sessions were done by videoconference between students and teachers, as the University did not resume practical cases until the end of the semester.

In order to assess what were the challenges faced by teachers in implementing such a rushed environment, class instructors were asked to make a statement on their findings after the classes. The teachers responsible for this course filled out an educational report, using pivotal remarks from chemistry educational goals. These questions were purposefully designed for this chapter investigation, aiming to record teachers' outtakes on issues like technological challenges, course evaluation and future strategies to prepare eventual digital transitions. Three principal topics were asked, encompassing the concerns and inequities of this challenging situation. The following topics aimed to ensure a clear perception on what strategies were done to peruse the transposition of in-person classes to an online basis.

1. Main educational strategy for digital laboratorial transition
2. Overcoming challenges and inequities
3. New strategies, especially in communicating with students, to ensure interest and participation

1. Main Educational Strategy for Digital Laboratorial Transition

As the lockdown caught the academia by surprise, there was no time to prepare an orderly transition for a digital stance. Hence, it would not be possible to transport any practical apparatus from the University, nor there was no time to record any eventual demonstrations. In fact, as the situation developed so hastily, the primary focus was to prepare digital contents for students, as this was not a simple lecture class.

The option was for teachers to record themselves executing planned experiments during the lockdown period. Only one teacher went to the university and prepared all the necessary apparatus. This took nearly a couple of days' work. The goal was for students to watch, instead of executing, experimental demonstrations of the planned laboratory work. After the online visualization and a primer theoretical introduction by the teachers (all during video-conference), students would be handed out virtual experimental documents. These would contain simulations of the raw experimental data that they would record if they were conduction the experiment. Then, students formed small groups and made the sequential data analysis of each experiment they watched. Ultimately, the evaluation of the students concerned the quality and effectiveness of the drafted laboratory reports (with data analysis).

As such, the creation of this digital laboratory content, based on demonstrations, is only possible if there is access to a quality technological infrastructure (sound capture, tripod and image capture, portable cables with adequate length), with no professional-grade equipment.

2. Overcoming Challenges and Inequities

Creating digital content: The digital content creation challenges were overtaken based on many attempts and self-training. The equipment and accessories were only partially supplied by the teaching institution. When addressing the first lesson/demonstration plans, they resulted from a pilot approach, thus needing to be improved. Ideally, these remitted classes should have an online part for direct student intervention. But that was postponed until a better opportunity arose. Also, the teacher must have some prior knowledge and practice of using digital-video equipment so that the use of this technology becomes routine and not a limiting step for the execution of a module (class, session). It is important to be careful with the quality of the lighting, the location of the systems, and the quality of image and video capture. For this, it is essential to use a portable microphone in order to guarantee excellent sound quality.

Class Timeframe Adaptation: In this case, the laboratory classes program has been maintained until the end of the semester. Only the intensity and the timeframe of the classes were changed.

3. New Strategies, Especially in Communicating with Students, to Ensure Interest and Participation

Two new strategies were designed, based on the teachers' observation and experience in these types of classes. According to the students, this type of approach worked very well with the teachers' style.

A1 – Focus experiment discussion, questions and dialogue with a single group (2/3 elements). Then, establish a rotation among those groups in the class (10 to 20 min). This leads to a concentration of interpersonal relationship between students, the groups and the teacher (while promoting a healthy competitive attitude between groups).

A2 - Promote the appearance of conversations on day-to-day themes, with introducing some teachers' personal stories in order to virtually transport students to a more scientific reality.

Inequities of Transition: Remote or Virtual Laboratories?

To make a systematic characterization of the options taken by the teachers in the case-study here described, we considered a categorization on their digital transition. Was it more beneficial to adopt a strategy more leaning to remote or virtual laboratories? In fact, the answer is not straightforward. Because of the lack of time to prepare for this transition, any remote strategy was not achievable. However, nor was it able to have a full virtual laboratory interface for students to interact.

The strategy taken in this case-study implanted a model that could be a merger of both remote and virtual capabilities. Although the students only watched demonstrations of the planned experiments, they had the chance to work with samples of raw data that they would attain if they completed the experiment in-loco. Thusly, the data analysis of a remote laboratory strategy is taking place here, having the teacher in the laboratory recording as the interfacing element. But perhaps the most dynamic part of the adaptation is the virtual laboratory inputs we identified. Granted, there is no software interface between students and experiments, but we have a digital mediated interaction between students, their peers and teachers. The virtual communication, made students debate their experimental data, as the teacher promoted discussion, making the educational as dynamic as possible. These are concepts that can easily be made into a digital transition of a theoretical class, but are not straightforward in a laboratory class. Hence, the strategy adapted here can be considered as a soft-merger of remote with virtual strategies. Despite not having the possibility of evaluation of student partial performance, it opens up the possibility of still maintaining the assessment of student data analysis.

But what can we name as the fundamental inequities of this abrupt online transition? They can be arranged in two primary groups: educational class adaptations; and hardware and video challenges. In the first case, as we reported, the recording of experimental demonstrations can come of the expense of relinquishing the "hands-on" dynamics. This remote strategy cannot give access and provide the same experience as an in-person experimental activity. As expected, the lack of time to prepare pivotal interfaces between student and experiment only permitted to execute prepared demonstrations. Despite this disadvantage, teachers could maintain a good part of the knowledge assessment of these classes. On one hand, students get to assist to the experiment and explanation of their teachers as they go. On the other, they still execute the data analysis needed to fill out their laboratory reports, as they would have done in a normal classroom setting.

The second inequity concerns mainly the availability and know-how of mediums to ensure the digital transition. As stated, teachers need to have some prior knowledge on how to make video content. Although this may come as easier to digital natives, elderly teachers may come across some difficulties if not properly assisted. Moreover, access to hardware capable of performing a good render of video outputs is required. Sometimes, if the teacher does not already have theses kinds of material (either personally or in the department), it can be difficult for the university to assist with this material in a brief time span. Also, another concern on digital hardware is the possibility that not all students may not have the materials, computers and/or the internet outside the facilities of the university.

RESEARCH REMARKS AND FUTURE DIRECTIONS

From the pilot task essay presented, we can name specific elements that need prompt attention when a teacher must make the transition of a traditional to a digital class. It is important that the teacher must have prior informatic and video skills, when the option passes by video demonstrations of chemistry activities. Perhaps the most learning outtake is that this type of classes cannot substitute the importance of "hands-on" practical activities. As such, one must endure this digital class reality as an opportunity of work on other important scientific skills. Introducing daily aspects of science and having them debated amongst the class, it is a pivotal way to gather scientific skills by an undergraduate student, coping to develop practical knowledge in a "hands-on" situation.

However, this outtake we presented needs further development. This only encompasses a simple assessment of key points that need to be addressed when considering change from traditional to digital mediums. A comprehensive study on how students behave digitally, regarding their interaction with the activities made needs to be achieved. With that information, newfound class design can be tailor made to address the digital transition of laboratory classes.

CONCLUSION

Digital educational methods are the bedrock for the future of higher education. Either from necessity or by innovation, they are likely to take over knowledge seeking students in this century. Schools, teachers and students need to comprehend how they can make this transition as smooth as possible, as digital innovations cannot, as we extensively viewed, solve an immediate transition of practical classes for a digital medium.

Going beyond technology driven methods, specifically targeting students from the exact sciences, we highlight the importance of methodological studies on digital laboratory class development. The unpredictability of having to change a class motif overnight can be eased with the development of prior skills, appointed in this chapter. It can also point to a reshape of a new digital type of laboratory online class, based on demonstrations (with or without a digital interface), class debates and development of methodological thinking.

For chemistry laboratory classes, the advantages of digital mediated remote or virtual transitions are commonly known amongst teachers. But sometimes, either from lack of preparation or opportunities to prepare a compulsory laboratory digital transition, there is no time to develop materials nor strategies. As we have seen in this chapter, the most plausible answer is to execute remote demonstrations of planned experiments, having students to analyse the fictional data they would have gathered. However, the inequities found in this transition can easily be exceeded with proper preparation. It is imperative that teachers and universities come together in an organized plan to assist in the digital transition of more classical disciplines. A good starting point, as we have noted, is the ability to record demonstrations of traditional experiments, having good prepared content to be shown and discussed in eventual digital class.

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ENDNOTES

[1] For example, in the case of EU-member Portugal, as of June 2020, all school degree systems adopted online learning status until further notice.

[2] More on schools whose activities were affected by the Coronavirus pandemic as of December 2020 on the following website: https://en.unesco.org/covid19/educationresponse.