Converting a formerly in-person biochemistry course based undergraduate research experience to online teaching during the COVID-19 pandemic

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Abstract
The COVID-19 pandemic had a significant impact on the delivery of undergraduate courses around the world, and this was no different for the Biochemistry Capstone course offered to Weill Cornell Medicine-Qatar’s second year pre-medical students during the 2021 spring semester. The course, which was previously delivered in-person and offered an opportunity for students to familiarize themselves with research and laboratory techniques, had to be modified to be delivered online. The online delivery of the course mainly consisted of “Zoom” sessions, “Canvas” materials, and data analysis using Microsoft Excel raw data sheets. The final assessment of the course consisted of a research report encompassing the procedures discussed, the results of the literature search, and data analysis carried out for the duration of the course. At the end of the course, students completed a survey on the online delivery of the course. It was evident that the majority of students preferred either a combination of in-person and online delivery or in-person delivery only, rather than a fully online course. Students’ feedback as well as other literature on the online delivery of courses were considered in order to potentially improve the course for the upcoming years.

KEYWORDS
biochemistry, COVID-19 pandemic, CURE, online teaching

1 | INTRODUCTION

Gaining research and laboratory experience while honing the communication skills necessary to complete projects in a group setting are crucial for undergraduate students in order to prepare them for future research opportunities. It is an essential constituent of the academic curriculum or syllabus. However, the unprecedented shift to online learning that had to be adapted as a result of the ongoing COVID-19 pandemic, presented itself as a hindrance to the latter. Despite the obstacles, remote learning tools have always existed, and many other useful resources have been put forward to aid instructors in accomplishing their duties on an online modality. In the current environment, most of the lectures are given using video conference software, such as “Zoom,” or provided as pre-recorded lectures for the students to watch at their own pace, while students continue to work on assignments and homework as usual. The laboratory section is...
more complicated, as it requires the demonstration of lab techniques without students getting a chance to perform the tasks themselves. Communication is limited between the members working on a project together, as well as between the professor and the students. Nevertheless, it is important to provide students with the knowledge and the experience required for their undergraduate training, and so the online capstone undergraduate course was designed and implemented.4–6

In the pre-medical program, at Weill Cornell Medicine-Qatar (WCM-Q), the Capstone Lab Experience was designed under course-based undergraduate research experience (CURE) guidelines for second-year students.7 The 13-week project course was originally developed to be delivered in-person, with goals of gaining hands-on experience with laboratory techniques and skills, learning to articulate scientific findings clearly through scientific writing, and enhancing analytical skills, teamwork, and problem-solving strategies. Therefore, the transition to an online modality posed novel challenges to faculty and students, increasing their stress and anxiety levels, knowing that the course is heavily laboratory based. Faculty and students alike have shown tremendous effort and determination to ease the transition, all the while making the virtual sessions efficacious, so that the outcomes are comparable, if not better, than the on-site delivery. Instruction is provided via synchronous and asynchronous lectures, after which lab data and results are provided to students to simulate their ability to work on raw data, present results, think critically, and develop research paper write-up and communication skills (Figure 1).

2 | IN-PERSON SETTING: BIOCHEMISTRY LAB BEFORE THE PANDEMIC

The Capstone Lab Experience course is a full semester course which incorporates two 50-min lecture/recitation sessions and one, three-hour laboratory session each week with in-person presence. This project-based course

Figure 1 Undergraduate students in course based research program can be engaged online through remote data analysis and critical thinking, literature review, and research paper write-up
is divided into three themes: proteins, membranes, and skeletons. The focus of this paper is on the biochemistry component, which is the “proteins” section, that explores key biochemistry concepts which are usually taught in lectures and are re-emphasized and underscored in laboratory settings. The experimental part of the biochemistry component work was organized into three parts and students were divided into three groups. The first group of students was tasked with purifying a sample of lactate dehydrogenase (LDH) protein from an unknown origin, which were either chicken heart or skeletal muscle. The purification usually takes 3 weeks and involved several steps which culminate in students checking the activity of the purified enzyme. The second group of students was tasked with determining the relative purity of the enzyme, studying its stability, and determining the composition of monomers of the isoenzyme using different techniques. Finally, the third group of students was tasked with analyzing the kinetic properties of the purified LDH sample and studying its kinetic inhibition using two different inhibitors. One thing that should be emphasized is that when a third of the cohort of students is doing the protein section of the capstone course, the other two cohorts of students will be doing either the membranes or skeletons sections. Although the students were not exposed exactly to the same skills, the protein part was made to help them get almost the same fundamental knowledge from different experiments by getting hands-on fundamental experience, enhancing their calculation, analytical, critical thinking and communication skills (Figure 2).

In each cohort, students work in pairs to complete the laboratory activities. Besides gaining hands-on experience during this course, which is a very important goal of any research project, pre-medical year two students were exposed to scientific literature through the activities. Furthermore, students were asked to read research and review papers related to a particular week’s experiment, plan out their own protocol, and possibly improve their protocols when faced with a problem. In addition, question-driven recitation periods were used to guide students to the meaning and relevance of their experimental results, and this reinforces the students’ critical thinking skills. Students were also able to refine their communication and cooperation skills throughout the course as they work in pairs. Finally, students learn to share their data and results through a research-like paper that they submit at the end of the course for evaluation. To summarize, the main objectives of the project-based learning are the following: practice with hands-on activities, develop critical and lateral thinking skills, broaden team-building capacities, interpret experimental results, and improve scientific report writing and presentation skills.

### 3 | DISTANCE LEARNING SETTING: BIOCHEMISTRY LAB DURING THE PANDEMIC

The biochemistry lab theme on protein analysis sessions involved a 50-min lecture/recitation session and a 3-h activity session every week. Structured similarly to the previous in-person modality, the experimental section was organized into three parts and the students were asked to work in pairs, with equal opportunity provided for each student to gain experience. Despite the lack of hands-on activities, the instructor presented the students with practical issues often faced during the different experiments and let the students think critically and propose solutions to remediate those problems in order to avoid or minimize errors. Students were also asked to produce step-by-step instructions with flowcharts for the experiments.

Raw experimental data was collected and provided by the instructor, and students are required to evaluate the data and present it as meaningful information to be able to determine the unknown origin of their protein. Students were expected to come prepared to both sessions with the required knowledge explained on the detailed protocols and instructions as well with pre-requisite tools including devices with the “Zoom” meeting camera turned on and notepads. It is important to highlight that there were some recorded sessions to help to stimulate conversation and maintain the integrity of the course in terms of communication.

The instructor used the “share screen” tool on “Zoom” to show PowerPoint slides and when required, added annotations while presenting to emphasize specific concepts. In addition, the “Microsoft OneNote” application was used on an “iPad” along with the “Apple Pencil,” which mirror the “chalk and board” tools normally used in classrooms and laboratories for further demonstration of difficult concepts. According to the large number of students overwhelmed by the sudden shift to online, this was a useful technique since it reminded students of how they were instructed before. Another advantage is that unlike in the previous in-person setting where visually impaired students found challenges in viewing important information due to the distance from the board, the improved quality and clearer annotations in the online setting were more accommodating. Moreover, the students used the application “Microsoft Teams” at their disposal to contact the instructor, whenever they deemed it necessary to better guide them or even alleviate the stress caused by the pandemic and some aspects of the online teaching.

The aims of the online modality of delivery were modified to aid the Class of 2025 students in enhancing...
their (1) Literature review (2) Data analysis (3) Scientific reasoning and (4) Data presentation skills (Figure 3). In the first week, students were required to construct a flowchart for the purification process and assess the purity and composition of the enzyme given the experimental data, demonstrating key fundamental biochemical and enzymological principles as each technique exploits a different biochemical property of the enzyme. The following week involved the analysis of the effects of pH and temperature on its activity, and finally in the last week, students investigated the mode of inhibition of two inhibitors, oxalate and oxamic acid on LDH by plotting Michaelis–Menten and Lineweaver–Burk graphs using Microsoft Excel. Students were then given a week to use

| Crude Extract Purification |
|----------------------------|
| 1. Ammonium Sulphate precipitation | 2. Desalting Column | 3. Affinity Chromatography |

| Enzyme Assessment |
|-------------------|
| Enzymatic Assay over different stages of purification process to determine purity |

| Purity Assessment |
|-------------------|
| 1. Bradford Assay | 2. SDS-PAGE Electrophoresis (with denaturation) |

| Biochemical Characteristics |
|----------------------------|
| 1. Optimum pH determination | 2. Optimum temperature determination | 3. Isoenzyme composition determination and the origin of the unknown LDH using gel activity |

| Bioinformatics using Expasy and other software |
|-----------------------------------------------|
| 1. Amino acid sequence determination of LDH A and LDH B | 2. Similarity between Chicken LDH A and B with the corresponding Human isoenzymes |

| Kinetics |
|---------|
| Determination of the right dilution of LDH in order obtain a steady state conditions that allow the determination of Km and Vmax |

| Effects of Inhibitors |
|-----------------------|
| 1. IC50 of Oxalate using Lineweaver-Burk Plot and determination of inhibition type | 2. IC50 of Oxamic Acid using Lineweaver-Burk Plot and determination of inhibition type |
their knowledge from the pre-requisite courses (Introduction to Experimental Organic Chemistry and Principles of Biochemistry: Structure and Function of Biomolecules) and in-depth literature analysis, to make sense of the data they collected over the past 3 weeks and formulate sound conclusions that would be presented in the form of a research paper. Since most skills are laboratory-based and require hands-on application, the remote delivery of this section had the objective of enhancing the students' techniques in the interpretation of scientific and experimental data, converting raw data into analyzed results, and arranging them in tables and/or figures format. In addition, the set of data and specific descriptions of protocols were given by the instructor in detail.

Despite the uncertainty and stress of the circumstances, the students of the class of 2025 in WCM-Q obtained the prerequisite experience and skills, all of which are necessary in their future research opportunities.

4 | BENEFITS AND DIFFICULTIES OF ONLINE DELIVERY METHOD

The main hurdle of the post-COVID-19 setup was undoubtedly the delivery of laboratory-based material via an online course. While the pre-COVID-19 setup provided ample opportunities for students to practice the lab skills they learned, the online setting of the post-COVID-19 setup lacked such an opportunity due to the restricted access to laboratories during lockdown. This can be shown in the students answer to the following question: “Did the overall format of this course provide adequate opportunity to improve your Laboratory Technique?” Only 21.4% of the students answered “Yes.”

However, while the focus of the pre-COVID-19 setup was mostly on the laboratory skills, the post-COVID-19 setup allowed more focus to be placed on literature review, data analysis, interpretation, presentation, and research report writing skills. Collaboration in the online setup was limited to “Zoom” meetings, Microsoft Teams...
discussions and emails, and lacked the engaging and collaborative environment of in-person classrooms and laboratories. These barriers also applied to the guidance received from the instructor. The instructor could better follow what the students were working on during in-person classes and could offer advice, whereas in the online setup this was limited to chat messages, and emails with screenshots or Excel files attached. Individual “Zoom” meetings with the instructor were also provided at the students’ request in order to partly close this gap in communication in the online setup. Alternatively, the instructors generally agreed that the students improved their scientific skills, research skills and demonstrated more independent thinking on their work and improved their ability to solve problems. This can also be shown on the students answers in some questions for the course evaluation. Indeed, when the students were asked if “the overall format of the course provided adequate opportunity to improve your Scientific Writing skills,” 85.7% of the 2021 class answered by “Yes.” Also, when they have been asked if “the overall format of this course provide adequate opportunity to improve your Research Skills?,” 64.3% answered by “Yes.” Lastly, 71.4% of the students answered “Yes” when they were asked if “the overall format of this course provide adequate opportunity to improve your Ability to solve problems using an indirect and creative approach?”

Additionally, online delivery of the course eliminated the need for students and instructors alike to be present in the university building, thus saving time and costs that would otherwise be spent on travel, making the class hours more flexible and time-efficient. Lastly, technical difficulties and interruptions were run into during the online classes, mostly due to internet connection problems or similar unavoidable circumstances (Table 1).

| Pre-COVID-19 setup | Post-COVID-19 setup |
|--------------------|---------------------|
| Gain experience with lab techniques | No lab work and hence no practical experience. Only discussion about problems that can happens during experiments and how to troubleshoot them |
| More engaging environment with easier collaboration | Limited online collaboration with more personal work |
| Focus directed mostly on practical lab work | Focus directed mostly on literature review, data analysis / interpretation / presentation and research report writing skills |
| Lab presence required for practical work | No requirement for physical presence, no travel time and expenses lost, more flexible hours |
| Face to face assistance during classes | Communication using modern tools like Microsoft Teams, emails, and Zoom meetings |
| More teacher guidance throughout with classroom interactions and lab work | Individual research is encouraged more |
| Technical difficulties limited to data analysis exercise only | Occasional technical difficulties and interruptions during class time and data analysis exercises |

5 | ASSESSMENT

Assessment of student performance in the LDH project was comprised of written reports and professionalism. In each cohort, students worked in pairs to complete the laboratory activities and submit group reports in the format of a research paper. The report was graded based on the quality of writing, data analysis, and critical thinking, as well as the ability for students to connect their analysis with the background that they gained through different biochemistry or biology courses.

Figure 4 shows student performance on the online biochemistry lab delivered in 2021 compared to the face-to-face biochemistry lab delivered in 2019. To minimize variability and increase the validity of the presented data, the comparison is of the same course, delivered by the same instructor. The data indicates that students under the online laboratory model performed very similarly compared to those under the previous model. The consistency of the grading scheme, though the 2021 students’ cohort did not have hands-on activity in their LDH project, explains the equivalent results. In addition, the high performance of the students who faced the online model is perhaps explained by the fact that the pre-medical students experienced some of the lab techniques and skills in traditional lab instruction in first-year biology, general chemistry, and physics courses as well as, experimental organic chemistry and physiology taught in the second pre-medical year, prior to their enrolment in the capstone laboratory. The prior background enabled students to immediately engage with the biochemistry content associated with the LDH-project and to focus on reading protocols and understanding them despite the absence of a virtual lab component, actively choosing and reading scientific literature, critically analyzing data, and results, and producing quality, scientifically sound reports of
those results. With all of these duties, students were required to improve their time-management skills in order to perform well. Actually, 85.7% of the students found that the online format of the course gave them an adequate opportunity to improve their time management. Besides that, the instructors generally agreed that the students were in time in completing their assignments and were active during their online meetings before assignment due dates.

Table 2 shows that the median score for the face-to-face learning is 98 and that of the online method is 97.25. The boxplot (Figure 5) is used to depict the variation in the data. It shows that the variability between the scores is more in face-to-face learning when compared to the online mode of learning. In order to study the significance of this variability, a Mann Whitney test was conducted, and the result suggests that there is no significant difference in average scores between the face to face Biochemistry component of the capstone course (median = 98) and the online course (median = 97.25).

6 | STUDENTS’ FEEDBACK AND COMMENTS

After the 2021 spring semester ended, it was crucial to have students’ feedback and constructive criticism to implement changes accordingly in case of the course being delivered online in the future. To assess the efficacy and efficiency of the online delivery, students’ comments and feedback were collected in the form of an anonymous survey consisting of three questions. The survey included a multiple-choice question concerning the preferred mode of delivery, a question regarding the rationale behind this preference, and any suggestions for improving the course for upcoming years in terms of delivery and execution.
From the 44 students 28 responded to the survey and 40% preferred in-person delivery only, 30% voted for both in-person and online delivery, 20% chose online delivery only, and 10% picked other, which was a preference for the in-person modality only under the condition that it was safe to carry out without the pandemic risk. The main finding extracted from the students’ feedback was that while some students support a combination of in-person and online laboratory sessions, the majority of students communicate a preference for an in-person delivery of the course, particularly the lab activities. The students in favor of in-person delivery claimed that, a major part of the course was meant to train students on laboratory techniques, which is only possible through in-person delivery. Other students mentioned that they feel that focusing and asking questions during online class was much harder and that being in class makes it easier to take things seriously and put effort in understanding instead of doing the work to finish it and that it would be more beneficial to acquire essential motor skills and overall laboratory competence though the hands on activities. The students preferring a blend of both modalities claimed that although it was possible for them to learn more through recorded videos when they go through content at their own pace, they still prefer doing group activities like recitation in person to have more interaction. Also, some other students claimed that although they can ask more questions during in-person labs, some labs do not require this and can be done online. In addition, these students suggested that giving step-by-step instructions and criteria for procedures would be expedient. Furthermore, the students opting for online delivery reason that “[it] saves more time and avoids the physical hassle” and “is self-paced, therefore less stressful.”

Conversely, a study done in the Department of Biomedical Engineering, University of Virginia, showed that 34% of the students preferred online learning, while 36% had mixed experiences and 26% struggled and felt that they missed out on indispensable laboratory applications. The authors also highlight the importance of laboratory video demonstrations, virtual office hours, and pre-recorded lectures, which the students found to be very useful.

According to these results, it appears that students have their own reasons as to why they prefer a specific mode of delivery. However, it is important to note that the modality of the course also depends on the severity and risk of the ongoing pandemic, as there are still new COVID-19 cases being reported every day. On the other hand, as more people receive the COVID-19 vaccinations, the risk is anticipated to be reduced. Since the course is initially designed to be delivered in-person (a laboratory-based course) and the majority of students prefer this option, having an in-person mode of delivery is the ultimate course of action when COVID-19 restrictions are no longer in place. The somewhat favorable response to the hybrid modality could also open up opportunities of implementing some of the online aspects into the usual in-person delivery in the future to increase the efficiency of delivery.

7 | DISCUSSION AND CRITICAL ANALYSIS FOR IMPROVEMENT OF THE ONLINE DELIVERY METHOD

As mentioned previously, the lack of hands-on practice of essential lab techniques, a core objective of the course, was absent in the online setup. One must recognize that circumstances such as the current pandemic may strike again anytime in the future, and thus instructors ought to be prepared to provide engaging yet challenging courses that meet the required objectives if such circumstances were to arise again.

The online format of the capstone course showed certain advantages of teaching, such as the strengthening of individual research, literature review, data analysis and interpretation, presentation, and research report writing skills. Although the strategy used in the biochemistry component of the capstone course attained most of the learning objectives of the originally in-person lab classes, with the exception of the hands-on activities, some improvements could still be done in the future to offer a more beneficial course. While some practical activities may not be crucial to students pursuing certain professions, such as pre-medical students who wish to become physicians, the skills gained from these activities could still be vital for students who may pursue a career in research.

One viable alternative to in-person lab sessions is online virtual labs that can be done for certain experiments, such as Labxchange, Merlot, and Learn Genetics, all of which are free to use and compatible with most devices. These programs could even serve to enhance the original in-person course, as these simulations are able to provide instantaneous feedback to all students on errors and any room for improvement of technique, which would be unrealistic to provide to every student in a pre-COVID-19 setup due to time constraints. Furthermore, the simulations do not require any equipment other than a computer device, which most students already have access to, removing the need for an expensive lab setup. Therefore, the incorporation of such virtual labs to both pre-COVID-19 as well as post-COVID-19 course setups as pre-lab assignments could serve be beneficial to practice lab techniques prior to
applying them. Studies have shown that engaging students in an active learning environment has significantly increased both learning outcomes and motivational levels. This could be explained due to students being less distracted by possible measurement errors that would otherwise occur in a normal lab setting. Another alternative would be to provide students with video demonstrations of the instructor performing the experiment in the case that a certain technique is not available in the virtual lab. This would allow instructors to control exactly what is being shown to students despite the students not being able to perform the techniques themselves.

While students' literature review skills are already assessed through the formulation of their conclusions, they can be further reinforced by assigning students to review method sections of experimental research papers in order to write their own optimal method plans before attending classes. Students would also be encouraged to focus on the lab safety procedures in every step of the process.

It is important to consider that while online simulations, video demonstrations, and literature reviews are satisfactory alternatives in the case that institutions are closed, they somewhat fail to replace the valuable experience gained from physically performing the techniques. In a survey conducted on students' opinions, it was found that although some computer-simulated experiments could be welcomed, students did not prefer a completely computer-based laboratory course.

8 | CONCLUSION

With the sudden transition to an online lab setup during the COVID-19 pandemic, experience in biochemical lab techniques was unattainable. However, despite the lack of face-to-face interactions, remote learning provided the opportunity to further improve on the students' scientific inquisitions as well as emphasize individual research. In addition, instructors' pedagogical skills in an online setting were enhanced mainly in relation with the design and organization of the course for better learning experiences, the adaptation of the assessments to the new learning requirements and the creation of distinctive learning environments, with the help of digital technologies. Since there has not been a comparable situation in the past requiring the complete reformation of the biochemistry lab course, there were many aspects that could have been improved upon, but all-in-all, the essence and objectives of the capstone course were maintained as was shown in the students' grades (Figure 4). Finally, due to the exploration and implementation of the online teaching modality in a CURE Biochemistry course during the spring of 2021, a well-designed hybrid modality encompassing an online teaching component that complements the conventional face-to-face instruction would most likely enhance future teaching in biochemistry courses involving a laboratory component.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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