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TEACHING REPORT

Hybrid Teaching in the Organic Chemistry Laboratory as a Response to the COVID-19 Pandemic

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Abstract

Opportunities for in-person learning dwindled significantly at schools during the COVID-19 Pandemic. Like most institutions, we were forced to pedagogically pivot (PP) to either virtual and/or hybrid learning. The following adjustments were made for the organic chemistry lab course at Worcester State University (WSU) during the 2020-2021 academic year: 1. Faculty teamed up to develop a system of dry labs; 2. Tutorial videos of experiments were created by the students, for the students; 3. A new setup for lab benches was put in place to maintain social distance when students are in the lab. These adjustments were crucial to maintain a safe and healthy environment for the organic chemistry lab class during the pandemic while providing a best practices lab experience for students. Videos and dry lab materials can and will continue to be used to help students as the university resumes its face-to-face courses in the upcoming academic year.

Keywords

organic laboratory, tutorial video, covid-19 pandemic, dry lab, green chemistry

The highly contagious COVID-19 virus totally transformed the way that people lived their everyday lives. In March of 2020, Worcester State University (WSU), like many other schools, transitioned to fully online learning in an effort to stop the spread of the virus, preserve the health of students, faculty, staff and family members (Kuhfeld, et al., 2020). At WSU, the pedagogical pivot (PP) to online learning was difficult but necessary. Faculty members were able to connect with students via online video conferencing software tools such as Zoom, Google classrooms, and/or Microsoft Teams, etc. By holding lectures and discussions online, students were able to learn and connect with each other as well as their professors. Although this was a very convenient solution for the problems that come with distance learning, there was still much to be done about the gaps left in students' education. Though the online platforms can be creatively utilized for lecture/discussion/tutoring (Leontyev, et al., 2020), we, like many others, struggled with how to transition (Spring 2020) the laboratory courses and then plan for a semester of social distancing, reduced capacities, and safety (Fall 2020/Spring 2021).

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Though there were several options for "wet" experiments for introductory/survey and general chemistry labs such as "at-home" kits (Kennepohl, 2007), no such options existed for organic chemistry labs.

WSU organic chemistry lab courses prepare students with knowledge and lab skills for a career in chemistry, biology or biotechnology. The student learning outcomes (SLO) include the principles of green chemistry; functional groups and stereochemistry of organic molecules; basic techniques of organic chemistry to conduct and monitor reactions, to characterize products and report the results. Faculty quickly recognized the areas of lab learning that needed extra support in order to allow students to develop a deeper understanding of the traditionally hands-on material. They identified the essential skills and topics that would benefit most from in-person instruction to ensure success in subsequent courses and postgraduate. To facilitate our PP, the following three adjustments were made for the organic chemistry lab course at WSU: 1. Faculty teamed up to develop a system of dry labs (Merriam-Webster dictionary) and appropriate wet labs (Merriam-Webster dictionary) for students working individually; 2. Tutorial videos of each experiment were created by the students who have already taken the course for current students; 3. A new setup for lab benches was put in place to keep social distance when students were performing their experiments in the lab. These adjustments had facilitated the organic chemistry lab tmester.

Wet Lab Setup and Procedural Modifications

Organic chemistry lab courses at WSU are typically taught by faculty in a 4-hour period one day per week for students to have ample time to run experiments, collect data, ask questions, and develop their lab techniques. Normally each lab section is capped at 20 students divided into ten groups of two students based on the lab space and availability of materials. As part of the Safe Return policies developed by WSU during Summer 2020, the lab spaces were limited to 12 students, which is not enough for all the students in a regular lab class to attend at the same time. Remote learning has been considered as other schools have shared in the special issue of the journal of chemical education after the initial submission of this manuscript (September 8th, 2020), but all organic chemistry professors at WSU agreed that in-lab learning is essential for skills development.

In order to adhere to the CDC guidelines and to facilitate in-person lab experiences, several new measures were put into place to aid in remote and in-lab learning. The WSU chemistry department decided to split the normal lab class into two groups of ten students to ensure the number of people in the lab was below the allowed room capacity, and to ensure social distancing was maintained throughout the lab period. Additionally, each student would work individually in a designated space. Each week, either group A or B would perform a wet lab in-person while the other group would be assigned an assignment, a.k.a. dry lab, to be completed off campus (Table 1).

Due to limited hood space, students are usually at the benches and working in pairs throughout the lab. In order to maintain social distancing and limit exposure during the 4-hour lab period, several modifications to our normal lab setup were implemented. Ten individual lab spaces were marked off and numbered. Though our glassware is usually communal and located on shelves, we decided to distribute some standard equipment (stirring hot plate, hoses) and glassware to each station (Supplemental materials). The only equipment that was "shared" were the balances, though extra balances were purchased and distributed such that only two students, at most, would be taking turns using the same balance during a given period. For each lab, we identified the chemicals and special equipment that were necessary and placed them in small plastic bins at each station. This aided our lab technicians tremendously in their ability to prepare labs ahead of time, keep chemicals and equipment stocked throughout the week; and when lab schedules were out of sync due to university holidays etc., execute a fast transition between protocols in between lab periods. Additionally, each station was equipped with a "waste" beaker for students to use throughout the lab period and to be emptied at the end of the lab by the student or the faculty member, again to limit movement within the lab space when it was at capacity. The overarching aim of this organization was to limit student movement when the lab space was full to only the faculty member. Most spectral data was provided for students, though some individual instruction was provided by the faculty member and students were allowed to collect spectra on their own during the spring semester.

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Development of a Dry Lab and Virtual Laboratory Training

In order for us to maintain our course caps of 20 students, we needed to split our students into groups of 10. Each group of 10 would come to campus one week for an in-person lab experience while the other group would study remotely. The number of in-person lab experiences was cut in half, necessitating the development of experiences that duplicated as much as possible an actual laboratory experiment. We were fortunate to have a subscription to the JoVE Science Education software that was purchased using funds provided by the CARES Act for the University's Safe Return to Campus Budget. Utilization of JoVE videos in virtual learning in chemistry and biology courses have been reported (JoVE videos, 2021; Mutch-Jones, et al., 2021; Ramachandran, et al., 2019). We utilized this software and additional resources to develop dry lab experiences for our students.

Pre-lab (for both dry and wet lab experiments): The focus of the prelab was to allow students to develop the theoretical knowledge and technical skills to perform a specific laboratory experiment. For the students performing the wet lab, this skill would be used that week as they performed the experiment. For students doing the dry lab, they would have a theoretical understanding of the techniques used for the subsequent experiment that would be provided via video. JoVE videos showing techniques were uploaded into the Blackboard shell so the students could easily access them. The JoVE subscription also provided questions that could be uploaded into Blackboard. We used some of the provided questions and developed our own to give a pre-lab quiz with seven to ten questions.

Lab Experiment: Students performing the actual wet lab would follow the provided protocol and run the experiment as they would normally. Students assigned the dry lab were provided a video that detailed the experiment for the week. The JoVE videos allowed students to observe experiments and techniques that we would not normally do due to safety or cost concerns. For example, students were able to perform a hydrogenation reaction as well as an oxidative cleavage using ozone virtually. The quality of the videos allowed students to make observations of color changes and changes in spectral data to determine the outcomes of the reactions without being exposed to flammable or toxic gasses/ chemicals.

Post-lab: Both sets of students were provided with directed questions that analyzed their understanding of the techniques, calculations, computer use (equation and chemical structure drawing), spectroscopy and chemical knowledge. Students who completed the dry lab were provided with data that they would have generated had they done the actual hands-on experiment.

Other dry labs were developed to teach spectroscopy, green chemistry topics and theoretical/percent yield. These were provided to students via Blackboard and submitted as a PDF electronically.

Student-generated Tutorial Videos

While we strictly followed the safety guidelines, it quickly became apparent that there was still a lot of room for improvement in this imperfect system due to lack of hands-on experiences for the students. The lab protocol that was already in use was very informative. However, it only illustrated the "how" as in how to perform an experiment. The JoVE videos were very helpful with dry-lab assignments, however, students responded that it was long and focused more on certain skills, plus it required a paid subscription. We wish that more related organic chemistry lab videos could be available to be used as a supplement to our lab materials. Some schools made their own videos for their undergraduate chemistry laboratories (Cresswell, et al., 2019; Pölloth, et al., 2020). Both Purdue University and BYU students made their own videos using lab instruments for the instructors to evaluate their lab techniques (Arnaud, 2020). A few vendors, including JoVE, were evaluated but they could not satisfy our green chemistry focused organic chemistry experiment needs. After a careful discussion among faculty and students, we decided to make our own lab videos so that our students could preview/review while they were working on the lab assignments. These videos would be based on the exact same lab station and materials used in our organic chemistry lab, and would be more in line with our green chemistry focus. In each of the videos, the theory, proper techniques, and the green chemistry principles would be emphasized.

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Creating a tutorial video requires more than just filming and cut-pasting. A video should be able to effectively coach, engage, and guide students in self-learning. It is also important to create a video that is not just what the instructor wants to teach, but also what the students want to learn. In order to achieve all these expectations, the video demonstrator, producer and narrator must have strong organic chemistry lab skills and knowledge. A team of organic chemistry research students who excelled in the organic chemistry lab courses, with video producing skills as well, were organized and entrusted this task with the supervision of faculty members. These students just took the organic chemistry lab, so they have the knowledge and know better what the skill challenges are. They are also at similar ages with our lab class students, so they know better what kind of tutorial video the students would be interested to watch.

All students in the video team were students signed up for the advanced chemistry research methods course for credit. As the project was going on, the University Advancement Office (UAO) announced a special program called "Experiential Learning Stipend" to reward students in the non-compensated advanced research or internship courses. Several students in the video team met the award criteria and received the stipend and were motivated even more.

The videos explained chemistry concepts and the "why" behind it that students can easily grasp with narration and visual aids. This was very important for the students to understand the material thoroughly and guide them to design the "How to do" in their future independent research studies. It was also important that students know that the videos were planned, edited, and produced by their peers with some input and strong support from the faculty in a "students teaching students" model. On top of that, the students in the team have successfully transformed the science experiments into attractive videos with vivid narrations, light music and accurate demonstrations. Light background music was added to cover that background noise and the break between narrations. To add more fun to the video, behind the scene clips during recording and a faculty demonstration of martial arts in Kungfu Panda uniform were added to the end of some videos.

Our first video focused on extraction techniques. A typical extraction lab would take about 45 minutes to complete, but filming a video took much longer time than the procedure that expected. The process began with the translation of the lab procedure protocols into a script format. The first obstacle started with the camera set-up process. A significant amount of time was spent on moving equipment, replacing flasks, or changing the angle of the camera to catch the high-quality shot. Challenges like this can only be experienced when the actual filming process starts. About 2~4 hours of raw video clips were recorded with three cellphone cameras and then uploaded into a shared Google Drive folder. The uploading was a time-consuming process because it would take a few hours using a regular laptop to upload, occasionally the laptop would overheat and collapse. Once uploaded, the clips were then carefully edited to ensure the quality video with narration and graphics or reaction schemes included.

In order to clearly deliver the green chemistry concept, explain the "why", and demonstrate the proper skills, our first tutorial video was edited to about six minutes with introductions and animations. According to statistics of video length, the rule of thumb is two minutes, the average length of business-related videos is just over six minutes, though optimal video length varies depending on the platform and content (VIDYARD, 2021). This video was released on 10/26/2020. All the comments said the video was easy to follow and was helpful to prepare for the experiment. We also received compliments from professors in the WSU Chemistry Department for the quality and contents in the video.

We continued to release more tutorial videos during the 2020 Fall semester and the 2021 Spring semester. The analytics of the ten videos uploaded on YouTube were collected and summarized in Table 2. Of the users who are taking organic chemistry lab courses, extraction and Aldol condensation videos got the most views, likes and comments because these two videos were released right before the experiment started. We were also very excited to see the views are several times more than the number of students registered for the lab class. Leaving comments and likes on a YouTube video required the students to login to their YouTube accounts, thus the number of likes and comments were less than the

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views. Four videos of those experiments in the 2020 Fall semester were released after the experiments had already been done in class, so fewer students went back to watch those four videos, but we would expect these numbers to go up as future students taking Organic Chemistry I Lab will benefit from them.

Even though we don't have a quantitative approach to evaluate the performance difference of students being in a lab setting with vs without these aforementioned approaches, we have received a lot of positive feedback from the students through the comments on YouTube videos and in-class communications. We have observed significant improvement in student lab skills, independence, and confidence throughout the lab. The quality of the assignments turned in have no difference even though the students have reduced in-lab time practice during pandemic. Some students report that with the breadth of JoVE videos and the depth of our videos, the combination works even better for them to understand and perform the experiment. Seeing someone they know on the video makes it more fun for the students to watch.

Besides those who are using the videos benefited, the students in the video team have benefited from this process as well, from their lab skills to the knowledge of green chemistry, from project planning to action, from teamwork to trouble-shooting skills, and their leadership skills. They have shared this amazing experience in the 2021 WSU leadership symposium (Murphy, et al., 2021).

Providing the senior students with the opportunities to help sophomores and juniors learning the knowledge and skills is a win-win for everyone. This was not just limited to our organic chemistry lab course or limited to creating the tutorial videos. We have been using peer-assisted learning (PAL, a.k.a. Supplemental Instruction (SI)) model for several years, for all levels of lecture courses in our curriculum (SI, 2022). The seniors who developed the videos have been part of the PAL programming since their freshman year, which has provided a framework for peer learning. We view the development of the lab videos for the organic laboratory an off-shoot of the peer-learning programming that we have cultivated within our department. We expect to find other aspects of peer-learning in the future to arise as students are exposed to both the PAL sessions and the lab videos. While we are, for obvious reasons, restricting ourselves to our own discipline of chemistry, we are submitting our efforts to a broader audience in a teaching journal to hopefully provide some ideas for other faculty who are interested in developing new formats within their own curricula. When there is a need, as faculty members or students, we can always coordinate the talents from everyone around us to figure out how we can meet the need. This will require faculty members to care and know more about our students, and the students are willing to communicate with the faculty and showcasing their talents.

Moving forward, we are switching back to "normal" mode. The split lab setup will NOT be sustained because we will have more students in the lab without the requirement of social distancing. Students will work with a partner; they can collaborate and assist each other with the experiment. An additional take away from this experience is the need for students to occasionally perform experiments individually to ensure they are mastering essential technical skills. Though group work develops the ability to work collaboratively and conserves resources and space, we recognized the need for some individual lab experiences. Additionally, the tutorial videos will continue to be used for the lab preparation, and the dry lab assignments will continue to be used to enhance and reinforce the knowledge and skills taught in the lab course. Based on the experience using the resources, students will no longer be required to purchase a hard copy techniques textbook and the labs will exclusively use JoVE content and online pre-laboratory quizzes to help prepare students for wet lab procedures.

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Table 1. 2020 Fall semester organic chemistry lab I schedule.

Date	LAB Group A	LAB Group B
Week 1	Intro & Green. Chem & Computer Skills & Biosyn of EtOH: Distillation*	Intro & Green. Chem & Computer Skills
Week 2	Functional Groups	Biosyn. Of EtOH*
Week 3	Recrystallization*	Functional Groups
Week 4	IR Spectroscopy	Recrystallization*
Week 5	Thin Layer Chromatography*	IR Spectroscopy
Week 6	1H NMR	Thin Layer Chromatography*
Week 7	Acid-Base Extraction*	1H NMR
Week 8	Identification of Unknown	Acid-Base Extraction*
Week 9	Aldol Condensation*	Identification of Unknown
Week 10	Identification of Unknown, Extra due to Scheduling for Holiday	Aldol condensation*
Week 11	Monitoring a Reaction by TLC/Microwave Chemistry*	Monitoring a Reaction by TLC/Microwave Chemistry*
Week 12	Lab Practicum*	Lab Practicum*

Wet lab (in-lab experiment). Labs without "" are dry-lab homework assignments

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Table 2. YouTube Analytics of the Videos as of January 28, 2022

Video Title	Date of Video Published	Views	Likes	Comments Added
[CH203*] Extraction	Oct 26, 2020	791	70	49
[CH203] Aldol Condensation - Green Chemistry	Nov 2, 2020	695	69	50
[CH203] CSI Thin-Layer Chromatography	Nov 17, 2020	412	37	17
[CH203] Biosynthesis of Ethanol - Distillation	Jan 11, 2021	487	34	18
[CH203] Recrystallization of Acetanilide	Jan 19, 2021	2525	73	13
[CH204*] Click Chemistry	Feb 7, 2021	331	29	30
[CH204] Oxidative Coupling of Alkynes	Feb 23, 2021	298	25	23
[CH204] Bromination of Stilbene	Mar 10, 2021	325	20	23
[CH204] The Friedel-Crafts Reaction: Acetylation of Ferrocene	Mar 28, 2021	646	30	18
Melting-Point Apparatusww	Jul 16, 2021	372	24	9
Total		**7041**	**421**	**259**

*CH203=Organic Chemistry Lab I; CH204=Organic Chemistry Lab II