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Teaching Tips - Special Issue (COVID)

Strategies for Delivering Online Biomedical Engineering Electives During the COVID-19 Pandemic

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CHALLENGE STATEMENT

The Severe Acute Respiratory Syndrome Coronavirus-2 (SARS-CoV-2) global pandemic has led to the need for social distancing and other health and safety measures to reduce the spread of the virus. This requirement has drastically affected the viability of traditional engineering course delivery methods. We were forced to adapt our teaching methods overnight as the province declared that all university teaching would be delivered online as of March 16th, 2020. Our Faculty of Engineering at the University of Victoria was in a unique position as the curriculum of our program runs year-round due to the requirement for students to take four mandatory single term work placements throughout their degree. As a result, we have offered a full complement of courses for students in the Year 2B and Year 4A terms during the Summer semester (May to August).

This paper focuses on two-fourth year electives (1) ''Introduction to Musculoskeletal Biomechanics'' and (2) ''3D Printing'', which represent two different types of courses that are core to engineering education and thus required different approaches to be successful in current circumstances. Specifically, the former course was primarily knowledge and problem based, whereas the latter focused on practical experience in design for 3D printing. This paper discusses what we learned at the halfway point in the implementation and delivery of these online courses. The primary challenge in the Biomechanics course was applying online methods that could enhance student comprehension of the material while ensuring that remote content delivery was at least as engaging as it was when delivered in person. The primary challenge for the 3D printing course was how to incorporate the engineering design process by adapting laboratories and group projects for online delivery while maintaining a good student experience.

It should be noted that the instructors of these two courses deliberately chose two different methods for delivery of their lecture material (1. Biomechanics used pre-recorded and live sessions, 2. 3D Printing used live sessions). This difference resulted from the fact that the Biomechanics course involved more concepts of greater difficulty and thus combined asynchronous-synchronous delivery methods that enhanced comprehension were chosen. On the other hand, the 3D Printing course material included many live demonstrations for promoting discussions and design ideas, and thus a fully synchronous approach was most appropriate.

NOVEL INITIATIVES

Introduction to Musculoskeletal Biomechanics, developed by Dr. Giles, traditionally consisted of 2–1.5 h in-person lectures, a 1-h tutorial, and 1 h of office hours each week. The lectures have been delivered through a combination of slides (with a skeletal version provided in advance) and whiteboard/overhead content delivery and involved regular student involvement and group activities to assist in student comprehension. Despite strong student satisfaction with this format, the author had considered replacing the format with a ''flipped classroom''[3,4] but had not taken any formal steps in that direction prior to the COVID-19 pandemic. The primary reason for considering a flip-

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ped classroom prior to COVID-19 was to enable students to come to the in-person ''lecture'' with strong established knowledge, which would allow them to undertake Active Learning in groups through more challenging activities. With a traditional ''content delivery lecture'' where students acquire knowledge just before an in-class activity the difficulty of the activity is severely limited.[1,5] With the restrictions resulting from COVID-19, the author sought to achieve two goals: (1) develop a set of content delivery and student interaction methods that provided a student learning experience equal to or better than that provided in previous years; (2) ensure that the methods and content developed don't act as a stop gap until the previous in-person delivery method can resume but rather is a springboard for an in-person flipped classroom.

The methods developed for this course adhered to a number of principles: (a) student interaction with each other and the professor are more effective and efficacious when they have first undertaken independent learning, (b) the professor should tailor content to student interests, questions, and areas of confusion, and (c) student time should be respected (i.e., course content delivery time should not exceed normally scheduled limits)—this is especially important within the online context as most tasks take longer than in-person.

With these principles in mind, the author chose a Hybrid Online format[6] to deliver course content through pre-record asynchronous shortened (~60 min) lectures and shortened (~20 min) synchronous (i.e., ''live'') question/activity sessions, as well as synchronous tutorial sessions and office hours. The use of asynchronous lectures ensured that connectivity issues that can plague live sessions were avoided and helped to alleviate the need for students to be present at a specific time (especially important given that students are now spread over multiple time zones). As well, this format allowed students to learn at their own pace and for the professor to incorporate small ''thought experiments'' into recordings.

As detailed in Activities 1–4 of Table 1, the asynchronous lectures consisted of multiple streams including lecturer video to provide interactivity and facilitate demonstrations, presentation slides, and a document camera for paper-based notes (Fig. 1). These streams were created and delivered using a combination of OBS Studio (OBSProject.com—free) and Kaltura software (Kaltura.com—paid). Kaltura allows students to choose which stream to focus on; however, the content could equally be created as a single ''Picture-in-Picture'' video using only OBS Studio and posted on YouTube.

The asynchronous lectures were posted 2–3 days in advance and coupled with Classroom Assessment Techniques (CATs) (i.e., quizzes and question forums).[2] The quizzes (grades given for completion) allow students to assess their understanding and enable the lecturer to identify the key areas of misunderstanding. By combining this with a forum where students can post their questions, it is possible for the lecturer to tailor the content of the live session including directly addressing questions, reviewing areas of difficulty, developing activities that reinforce student learning, and identifying additional resources that can assist students. As well, analytics were assessed to identify subsections of the pre-recorded lectures that students were watching repeatedly and thus were likely struggling to understand. Although any good lecturer can address most questions in real-time during live sessions, their ability to identify issues/questions in advance using this new format means that the lecturer can provide a greatly enriched experience.

Within the live sessions, the delivery of the above content is assisted through the ability to share varied media (e.g., slides, webpages, webcam, and hand written notes), to gain informal (e.g., raised hands) and formal (e.g., polls) feedback, and by enabling students to take part in group discussions through ''breakout'' group functionality.

The 3D Printing elective course was newly created at the outset of the pandemic by building an experiential design focused course that drew material from an existing introduction to 3D printing technologies course along with content from an existing course in Bioprinting. The original format involved in-person lectures twice a week, which was adapted for remote course delivery through 2 1.5-h synchronous lectures with a 1-h interactive tutorial. The course also included guest lectures from local and regional industrial partners involved with the 3D Printing industry at various levels, including Cellink, LaserCamFab, Rainhouse, and Javelin Technology. Referring back to Table 1, this course used activities three, four and five, and the associated technologies listed to facility the chosen delivery method. The course also incorporated an individual design project targeted toward commercially available 3D printing technologies and a group project using 3D Bioprinting to generate an engineered tissue. Finally, students completed three assignments covering the material detailed in lectures. Despite the pandemic, it was important for this 3D printing course to provide extensive design experience and the opportunity to produce multiple design prototypes through an iterative process.

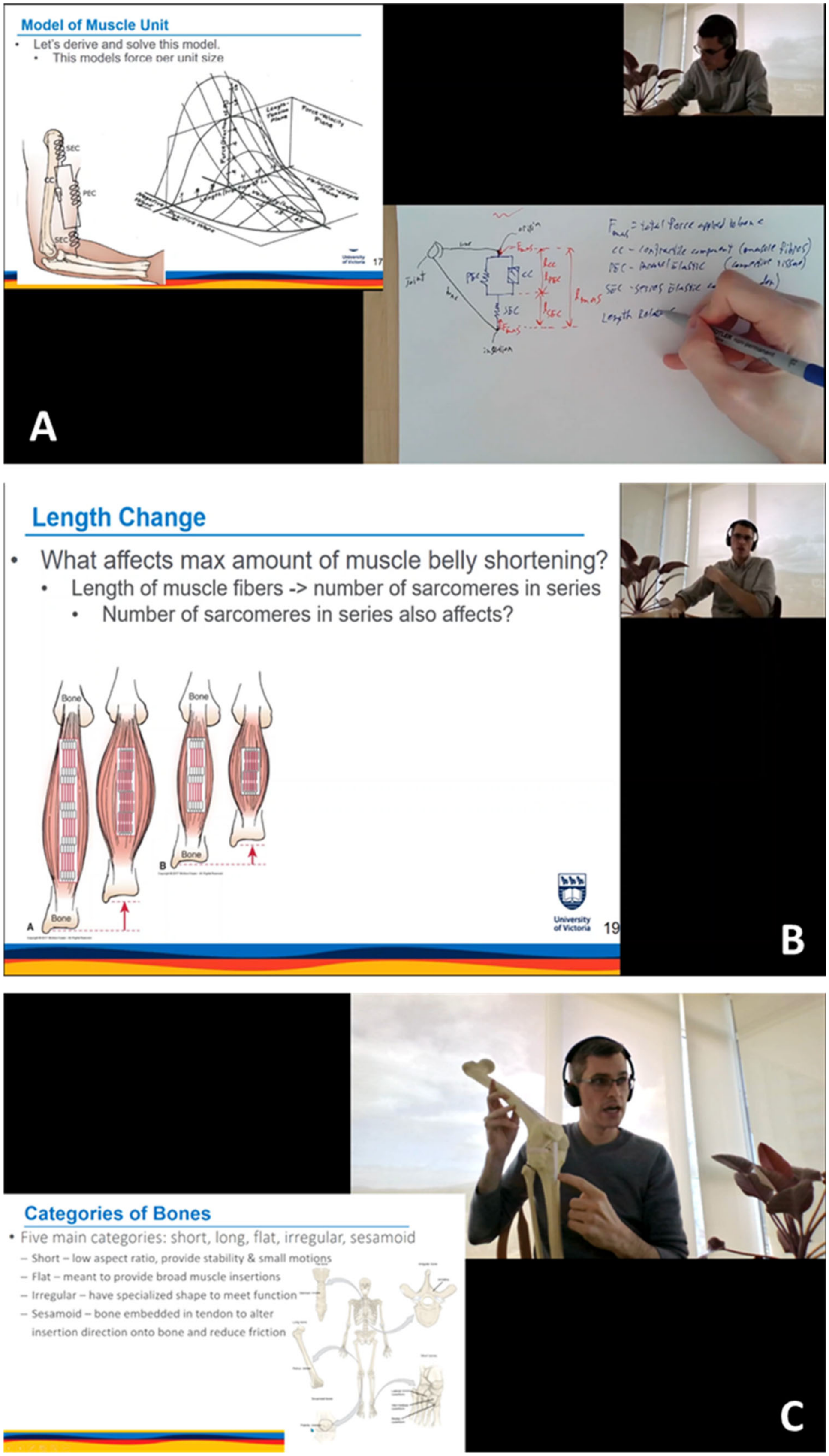
As synchronous delivery was chosen, the key challenges in this course were not developing the correct balance of delivery methods as was the case for the

TABLE 1. Table of activities that form the foundation of the two elective courses and the requisite technologies.

#	Activity	Sub-activity	Enabling technology
1	Pre-recorded lectures	Provide students individual thought experiments Preview group activities for live sessions	Multi-stream screen-capture software (e.g., OBS Studio (free) or Kaltura/PanOpto (paid)), online posting (e.g., in Learning Management System, or YouTube), webcam, document camera or tablet & stylus (author prefers document camera to make video more engaging), wearable microphone (e.g., Bluetooth headphones to improve sound quality)
2	Pre-Live session CATs	Quizzes Forums	Learning Management System, survey website (e.g., Survey Monkey), course website
3	Live session	Synchronous content delivery and demonstrations (for 3D Printing course only) Q&A derived from CATs Q&A asked during live session Breakout group activities/discussions with follow-up lecturer led discussion Polls	Webcam, document camera or tablet & stylus, videoconferencing (Zoom, WebEx, Skype, etc.), wearable microphone
4	Tutorials	Q&A Practice problems (posted in advance)	Webcam, document camera or tablet & stylus, videoconferencing (Zoom, WebEx, Skype, etc.), wearable microphone
5	Projects	Team Member Engagement & Feedback	Engagement software (e.g., Slack (free/paid), Microsoft Teams, Learning Management Software)
		Prototype Creation & Iteration	On campus 3D Printing with remote delivery of feedback by teaching assistants and mailing of prototypes to students

above described Biomechanics course, but rather the challenge was to facilitate students' ability to conduct multiple design projects including prototyping of their devices, despite having no access to campus. This challenge mostly clearly affected the individual project whose purpose was to encourage students to implement the knowledge learned during lectures by defining and implementing design objectives, being able to refine their design based on professor and teaching assistant feedback, and to communicate clearly in a final report. This challenge was overcome through a series of personnel and procedural changes as outlined in Activity 5 of Table 1. First, we empowered the course's teaching assistants to play a much more active role in the student experience by regularly engaging with students and providing feedback on their designs in addition to their regular tutorial and marking duties. This did necessitate an increase in the number of teaching assistants in the course and the number of hours each was paid. Second, we utilized specialized software to facilitate engagement between students and teaching assistants and amongst students, which included our University's learning management system and a course specific Slack workspace. Third, after each student generated a detailed design that leveraged the strengths of additive manufacturing, the goal of students printing and iterating multiple prototypes was achieved as follows: (1) students were required to submit their CAD files along with a CURA slicer file and gcode to a teaching assistant, (2) the teaching assistant would use these files to print the structures using an Ultimaker 2+ or Ultimaker 3 with black poly (lactic acid) (PLA), (3) parts along with teaching assistant feedback were then made available for pickup for students located in Victoria or were shipped to remote students. A volume constraint of $10 \times 10 \times 20$ cm was placed on the design in order to minimize the cost of shipping while maintaining the ability to produce a meaningful prototype. Although this did not happen during the course, in case of a full university shut down, the teaching assistants would have been allowed to check out the necessary equipment for 3D printing and photos of the final prints would have been emailed to students for inclusion in their design reports. Using these methods, students successfully completed the individual design project including two iterations of their design and submission of a final report. Figure 2a and b shows an example of the first iteration of a foldable crib board designed by a student that was printed for the course. Figure 2c and d show how the design was refined during the second iteration.

The course's mandatory 3D Bioprinting group project focused on each group creating a different engineered tissue by considering the biological and structural factors critical to printing them. The students all completed a literature review assignment surveying the state-of-the-art in 3D Bioprinting of their chosen tissue, which prepared them to complete their project. Subsequently, they proposed a novel way of using bioprinting technologies to generate a specific tissue or prosthetic in outline form and received feedback on how to improve their project for the final report. Each team prepared a final report that included


Model of Muscle Unit
Let's derive and solve this model.
This models force per unit size
SEC
CC
PEC
SEC
17
A
Length Change
What affects max amount of muscle belly shortening?
Length of muscle fibers -> number of sarcomeres in series
Number of sarcomeres in series also affects?
Bone
Bone
Bone
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University of Victoria
19
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Categories of Bones
Five main categories: short, long, flat, irregular, sesamoid
– Short – low aspect ratio, provide stability & small motions
– Flat – meant to provide broad muscle insertions
– Irregular – have specialized shape to meet function
– Sesamoid – bone embedded in tendon to alter insertion direction onto bone and reduce friction
C

◀**FIGURE 1. Three screen captures showing multi-stream configurations created in OBS Studio and used for course. (a) Three stream configuration used when handwritten derivations are being conducted. Slides and lecturer video provide context. (b) Two stream configuration of slides and lecturer video used when handwriting is unnecessary and focus is on slide content. (c) Two stream configuration of slides and lecturer video used when handwriting is unnecessary and focus is on demonstration by lecturer. Configurations can easily be changed during recording using OBS Studio hotkeys.**

an (1) Introduction and prior art, (2) Selection of structure, bioink, cellular components, and the bioprinting process, and (3) Analysis and characterization of the target tissues. The final report was limited to 10 pages (~3000 words) and was required to contain at least 25 references to the scientific literature. The teams will also completed synchronous teleconference presentations on these projects followed by a question period from the professor, teaching assistants, and other students.

REFLECTION

Based on the results of a mid-semester student survey (Research Ethics Approval #20-0356), the Biomechanics course has been very well received with 92% of students stating it is "as good or better than an in-person class" and 73% stating they would recommend the course (in its online format) to other students'. As well, the use of asynchronous lectures and accompanying live sessions was effective and well received with 86% of students stating that the combination was "somewhat, very, or extremely helpful." 70% of students found the use of quizzes and forums before each lecture to be valuable. It was found that this method only increased the time required of the lecturer by ~25%; however, the author views this as an investment as the recorded lectures will be reused and thus reduce the time commitment in future years by ~50%. To help limit the extra time required, it is important that the forums incorporate some sort of "up voting"/"like" feature to ensure students do not repeatedly post the same question. This feature did not exist within the author's own Learning Management System and thus they reinforced that students should reply to existing student questions with "I have the same question" rather than posting again. As well, it is critical that a new forum topic be created for each lecture.

The greatest difficulties observed with this method were (1) the author underestimated the difficulty of creating short quizzes that effectively identified the areas where students were struggling, (2) because students had the pre-recorded lectures, they were consis-

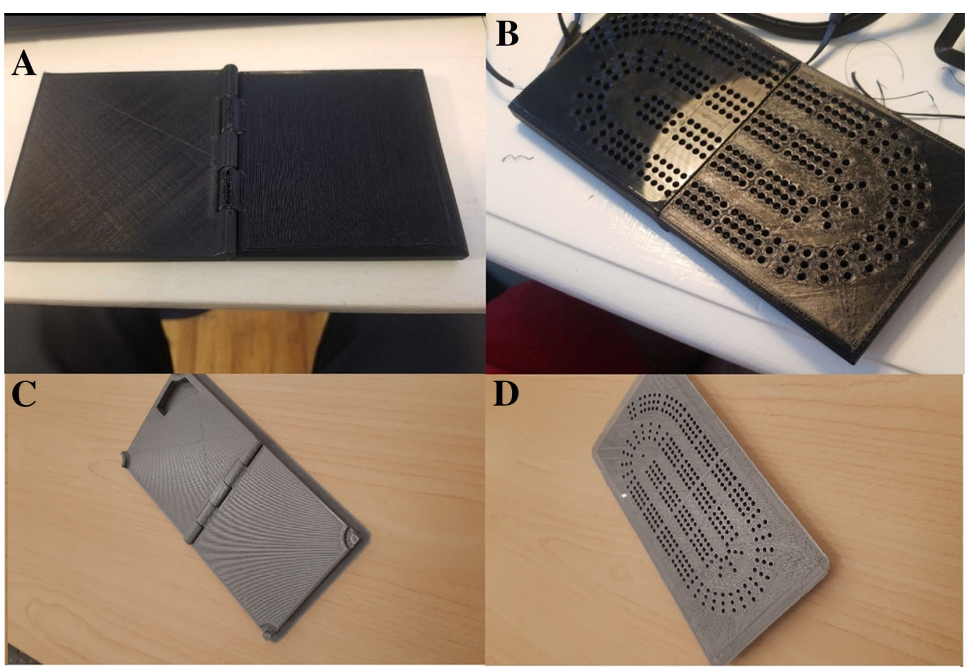

FIGURE 2. An example of the individual 3D printed design project consisting of a foldable crib board. Students either picked up or were mailed their prints—allowing them to analyze their projects and improve upon their designs. (a) The hinge region of the board and (b) the game board from the initial prototype. (c, d) show the same features on the design from the second and final version of the print.

tently more prepared for live session activities and thus the activities (derived from previous iterations of the class) could have been more advanced. The author plans to overcome these two issues in future iterations of this course whether online or in-person. This initiative will continue to benefit students after COVID-19 as the author intends to continue using this combined asynchronous and synchronous approach to achieve a flipped classroom model.

In terms of the 3D printing course, attendance remained high (~80%) throughout the semester. Students often asked questions in the Zoom sessions and were interested in the lectures provided by industry. They also appreciated the dedication of the teaching assistants and their expertise in the tutorials and in the quality of feedback provided on their projects throughout the design process. Having teaching assistants with extensive 3D printing expertise made course delivery a smooth process. Some difficulties were encountered with regards to the timelines for the individual design project. We extended the initial deadline and thus it pushed back the corresponding deadlines for project milestones for the rest of the class. The development of a dedicated fourth-year elective in 3D printing will benefit the curriculum for years to come by providing relevant training in this cutting-edge field.

Overall, these case studies used accepted pedagogies within the COVID-19 context to create knowledge acquisition-based and design experience-based biomedical engineering electives using a variety of strategies and online tools. These case studies can help guide instructors working within the context of COVID-19 in choosing the most appropriate delivery method given the nature of their course offering. More specifically, the case studies showed that both fully synchronous and hybrid asynchronous/synchronous methods can be successful with the latter being appropriate for content heavy technical electives.

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