Enhancement of Stay-at-Home Learning for the Biomechanics Laboratory Course During COVID-19 Pandemic

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CHALLENGE STATEMENT

The outbreak and rapid spreading of the Coronavirus disease 2019 (COVID-19) in the U.S. disrupted American education enterprise with a majority of higher-education institutions physically shutdown and students and faculty transitioning from in-person lectures to remote learning during Spring 2020.¹ *Experimental laboratory courses* provide biomedical engineering (BME) students essential experiential learning experiences to enhance critical thinking and innovation and to explore deeper engineering concepts.^{2,3} However, the COVID-19 pandemic has forced most BME programs to implement social distancing by switching from face-to-face to online instructions. Although studies on education during COVID-19 have shown effectiveness of online/blended learning environments for traditional lecture-based courses,^{4,5} our students expressed their concerns in recent laboratory post-course evaluations. Students and faculty felt unprepared after completing laboratory courses as they were only analyzing pre-collected data or provided with visualization of pre-recorded experiments. This may be attributed to the lack of hands-on experiences and peer-interactions in the traditional distance-learning environment. Uncertainties remain on how academia needs to react to the pandemic in Fall 2020 and beyond. Therefore, we aim to address this

significant challenge by discussing our ongoing development of a multi-modal experimental platform for the Biomechanics Laboratory course to enhance student learning in a *stay-at-home* or reduced-contact educational environment.

NOVEL INITIATIVE

We will employ and evaluate four educational models to enhance student learning during Fall 2020. Specific efforts will be focused on the development and implementation of (i) “stay-at-home” experiments, (ii) remotely-accessible experiments, (iii) multiscale visualization of biomechanical testing data and complex material’s behaviors, and (iv) instructor feedback and peer assessment (Fig. 1). Each of these four instructional modes will be discussed in the subsequent subsections.

“Stay-at-Home” Experiments

We will first develop low-cost, 3D-printed experimental setups for testing biomimetic samples, such as soft biocompatible polymers, as “stay-at-home” experiments. Experimental setups of manually-driven testing stages will be 3D printed using commercial fused deposition modeling (FDM) 3D printers (Fig. 2). All the 3D-printed parts and experimental samples will then be mailed to students’ home. Students will have hands-on opportunities to assemble the 3D-printed parts and build the experimental platforms for mechanical tests. Biocompatible polymers, such as

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FIGURE 1. The proposed educational approaches for "stay-at-home" BME laboratory projects.

FIGURE 2. Schematic of the 3D-printed biomechanical testing stage: (a) tensile testing using sheet samples, and (b) compressive testing using gelatin cubic samples (The SolidWorks drawings are available at: <https://app.box.com/s/p22494dnnfgz3nkutpbecay78drqmun9>).

polydimethylsiloxane (PDMS) sheets and cubes, will be provided so that students can conduct mechanical testing experiments and visualize material's behaviors under different loading conditions (Fig. 2a). Moreover, raw materials and instructions for the fabrication of gelatin cubes will also be mailed to students. By adjusting the material's concentration, gelatin cubes with various mechanical properties can be fabricated at home. Students will utilize the mechanical testing stage for compression tests and use a ruler to measure the

material's axial and transverse deformations under compressive loads (Fig. 2b). Fundamental biomechanics concepts, such as the Poisson's ratio that is defined as the minus of the ratio of transverse strain to axial strain, can be experimentally studied using the designed tensile and compression tests. It is expected that the proposed "stay-at-home" experiments can enhance the understanding of fundamental biomechanical testing procedures and mechanics concepts, and that assembly of the setup will expose students to

engaging and genuine experiences in 3D printing and mechanical components.

Remotely-Accessible Experiments

We will next devote significant efforts to developing novel remotely-accessible experiments for more complex biomechanics experiments, such as the stress-strain relationships. Lecturers and teaching assistants will set up a camera and online meeting platforms, such as Zoom, for students to visualize the experimental procedures at home. In addition, remote control functions of the experimental testing equipment (e.g., the CellScale's UniVert system¹) will be turned on, allowing remote operation of testing by students. We will develop two remotely-accessible laboratory assignments (Table 1). For example, a three-point bending test of chicken bone or artificial bone material can be set up using the UniVert mechanical testing stage¹, and the real-time experiment will be broadcasted to each student group using a camera. In these experiments, students will remotely log in to the computer and set up the testing parameters (e.g., loading rate, displacement range and data acquisition rate). Students can then launch and abort the experiments, while the instructors and teaching assistants, who are physically next to the testing equipment, will ensure safety and install new samples in between the two experiments. During the remote experimentations, a series of scaffolding strategies will be implemented. First, student groups will be engaged in remote operation, real-time observations of both the tested samples and the recorded biomechanical quantities through the LabJoy graphical user interface (GUI).² Then, students will participate in post-experiment group discussions, followed by their video presentations. Such instructional efforts are expected to enable remote access of major equipment for biomechanical testing, allowing students to conduct complex experiments that are available at home during the COVID-19 pandemic. A certain level of training from these remotely-accessible laboratory assignments will help prepare future biomedical engineering workforce, such as to be familiar with the remote working environments and establish their effective teamwork and group communication skills.

Multiscale Visualization and Experimental Module

We will next deploy a multiscale visualization and experimentation module to enhance students' under-

standing of material behavior under complex loading conditions across multiple length scales, ranging from micrometers (micro-level) to millimeters (macro-level). Biomaterials, such as artificial skin or harvested bovine tendon tissue, will be tested using micromechanical tensile stages. At the micro-scale, the samples will be observed under an optical microscope, so that microstructural features, such as collagen fiber architecture, can be visualized during testing. At the macro-scale, a digital image correlation (DIC) system will be employed to obtain the two-dimensional strain fields, allowing students to visualize both the material's responses and microstructural changes simultaneously. All the videos, images, and mechanical testing data will be collected by the instructors and included in a multiscale visualization and experimentation educational module. Directions, guiding questions, and examples will also be included in this educational module. By employing the developed educational module, students will be supported to virtually conduct multiscale biomechanics experiments in a simulated environment. The material's relations across the two length scales will be illustrated after the virtual experiments are completed. Students will also learn how to calculate the local strain field by using the DIC-tracked fiducial marker positions and compare their results with the strain data provided by the instructor, which serves as expert modeling.⁶ This effort is expected to assist students to deepen their understanding of material's microscopic behaviors and their biomechanical responses.

Instructor Feedback and Peer Assessment

In Spring 2020, we collected some data to understand the impact of “*stay-at-home*” BME laboratory courses on student learning through anonymous mid-semester and end-of-semester course evaluations. The mid-semester evaluation indicated that the main negative impact of the virtual laboratory was the lack of peer interactions that stifled motivation to learn. In the past studies, social interactions have been shown to improve student ability to monitor their own understanding of materials and to motivate them to assume responsibility for their own learning.⁷ Therefore, in the second half of the semester, we added the laboratory activity of group discussions in Zoom breakout rooms to increase peer interactions. The lab groups of two to three students worked in a breakout room to analyze the experimental data, while the lab instructors “moved” to different breakout rooms, similar to circulating from one group to another in a typical in-person lab setting, and provided each group with feedback and probed their understanding of the course contents. In addition, we also required students to

¹Univert from CellScale Biomaterials Testing: <https://cellscale.com/products/univert/>.

²LabJoy is the software of the UniVert mechanical testing system.

TABLE 1. Proposed remotely-accessible laboratory assignments of biomechanical testing, providing BME students unique and genuine experiential learning.

Lab assignment	Description	Learning concepts
Uniaxial tensile testing (<i>Linear Regime, Small Deformation</i>)	<ul style="list-style-type: none"> • Three artificial skin dog-bone specimens (with an effective cross-sectional area = 1.0, 5.0, and 10.0 mm²) will be tested by a group of 3 students to observe the material's response under the linear stress-strain regime • Students will analyze the data (.csv) in Excel to learn the calculations of uniaxial strain and stress 	<ul style="list-style-type: none"> - Linear stress-strain relationship (i.e., Hooke's law) - Importance of using the derived stress and strain relationship, rather than the directly-measured force-displacement curve, for bioengineering design
Three-Point Bending	<ul style="list-style-type: none"> • Chicken bones or artificial bone-like materials will be pre-fabricated and used in this experiment • Mid-span displacement will be gradually applied, and the force will be measured • Students will use the measured data to make the force-deflection curve 	<ul style="list-style-type: none"> - Evaluation of the validness of the elementary beam theory

Student groups will hold post-experiment virtual meetings to discuss their findings and analyzed results, and then prepare a 5-min video presentation to be shared with the entire class on the Canvas course webpage..

conduct peer-assessment as one of the laboratory assignments.^{8,9} Students were asked to write lab reports and then review each other's report, guided by a set of question prompts and rubrics for peer-assessment (see an example in *Supplementary Material*), which were designed to further enhance student's peer-interactions.¹⁰ From the final course evaluation in Spring 2020, the students noted increased peer interactions and motivation to learn as a result of using the Zoom group discussions. The course evaluation from Spring 2020 provided initial evidence that “*stay-at-home*” BME laboratory courses, integrated with peer interactions, peer assessment, and instructor feedback in Zoom breakout rooms, could be a feasible alternative solution for student lab experiences in times of crisis when in-person labs are unavailable. Overall, the implementation of both breakout session peer interactions and peer evaluations will not only improve student's learning experience, interest and engagement, but it will also help to offset the unavoidable decrease in peer connectedness resulting from stay-at-home isolation during the COVID-19 pandemic. These evaluation techniques will be continuously adopted, revised, and integrated with the developed educational modules of multi-modality biomechanics laboratory experiments.

REFLECTION

In this article, we have presented an innovative instructional model of multi-modality experiments to provide student virtual laboratory experiences remotely from home, which aims at minimizing the impact on student laboratory learning caused by the

COVID-19 pandemic—a *pressing challenge* faced by many BME undergraduate programs in the United States and around the world. This model offers a holistic and systematic scaffolding framework¹¹ that consists of four main integral processes: (i) developing 3D-printed experimental setups; (ii) conducting remotely-accessible experiments, and (iii) multiscale visualization of biomechanical testing data and complex material's behaviors, and (iv) instructor feedback and peer assessments. Each of the four processes has its own micro module with scaffolding strategies embedded, such as guiding questions, prompts, instructor feedback and peer interactions. Each subsequent process is intended to further foster students' laboratory experience and deepen their understanding of biomechanics theories.

Although limited and preliminary, the Spring 2020 course evaluation indicates that the proposed instructional model and technology platform have the potential to be extended to other BME and general engineering experimental courses, providing a unique framework for the implementation of stay-at-home, online and remote *experiential learning* of laboratory experiments. We plan to further collect evidence to evaluate and validate the “*stay-at-home*” BME laboratory model in the following two semesters, focusing on the following two questions: #1 Does the “*stay-at-home*” BME laboratory have the similar or better effects than the traditional in-person laboratory? #2 What is student's learning experience with the “*stay-at-home*” laboratory? Over the next two semesters, we will collect data from three experimental conditions, and we will set up for each of the laboratory course: (a) “*stay-at-home*” laboratory with peer interactions and peer assessment, (b) “*stay-at-home*” laboratory with-

out peer interactions and peer assessment, and (c) traditional in-person laboratory. The comparisons will allow us to examine the effectiveness of the “*stay-at-home*” laboratory and evaluate student learning outcomes in different laboratory learning environments. To answer Question #1, we will collect the pre-test and post-test on the learning concepts and procedures indicated in Table 1. In addition, we will also collect data from the three laboratory environments: the lab reports (using the rubrics shown in *Supplementary Materials*) as graded by the instructors and student presentations (video presentations for the two “*stay-at-home*” laboratory environments). Furthermore, we will collect survey data from the two “*stay-at-home*” laboratory environments, with questions focusing on learner interest, motivation, engagement, self-efficacy, self-regulation, peer-interactions, peer assessment, and cognitive load in order to answer Question #2. Inferential statistical analysis will be conducted to compare the pre-test and post-test and learning experience surveys across the three learning environments. If time and resources permit, we will also collect and analyze interview data from the “*stay-at-home*” laboratory.

Further evidence is needed by collecting empirical data to validate the proposed laboratory model in the near future. Through further research validation, it is hoped that this educational model, including its technology platform, will be adaptable for other future critical incidences like the COVID-19 pandemic (i.e., *adaptive education for emergencies*). This innovative instructional model is also expected to mitigate the longer-term negative consequences on BME student’s intellectual development and career preparation. Furthermore, our educational modules of multi-modality experiments tightly couple theories to hands-on experiments with an emphasis on involving students in experiential learning.¹² Such innovative developments will aid in making the important connection between theories and the real-world phenomena, which is a known issue in STEM education such as the learning of advanced mechanics or machine design without laboratory experiments.^{13,14}

ELECTRONIC SUPPLEMENTARY MATERIAL

The online version of this article (<https://doi.org/10.1007/s43683-020-00025-w>) contains supplementary material, which is available to authorized users.

CONFLICT OF INTEREST

The authors declare no conflicts of interest or competing interests.

AUTHOR CONTRIBUTIONS

All authors contributed to the idea curation. The first draft of the manuscript was written by C-HL, YL, MM, and all authors commented on the revisions of the manuscript. All authors read and approved the final manuscript.

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