A Hybrid Teaching Method for Undergraduate Biomechanics Lab

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Abstract—The main goal for this work was to provide information as to the possibilities of creating an online or hybrid option for an upper-level biomechanics laboratory that is in keeping with course goals. Conversion of the laboratory modules for online use was described with detailed setup and learning goals. The lecture portions and most labs could be easily converted to online-only options. Some of the other labs could be offered as part of a hybrid delivery method with reasons for what these labs could provide in-person students. Options are also given so that the course can be made completely online if needed. Troubleshooting of mechanical experiments is lost with a completely online presentation; however, experimental design and many other biomechanical techniques are maintained with the online environment.

Keywords—Biomechanics, Laboratory, Hybrid, Online, Experiential learning.

CHALLENGE STATEMENT

Most bioengineering programs include laboratory courses to provide ‘hands-on’ experiences to our students so that theoretical knowledge can be applied to improve learning. Biomechanics is a rich and varied field of study ranging from cellular to whole body mechanics. However, structuring laboratories to provide adequate hands-on experiences for all students can prove difficult within this field. Undergraduate students in bioengineering have physics, including Newtonian physics, as part of their curriculum, but not all students are exposed to higher level mechanics, such as statics, dynamics, or strength of materials (also called solid mechanics). The teaching challenges

associated with this lack of, or differences in, foundational knowledge is compounded by potentially expensive and resource-heavy biomechanical techniques. However, the value added to the student knowledge with hands-on material and experiences has been clearly demonstrated.^{3,10,5,7,11} These previous studies have shown that virtual-only laboratories are not as effective in supporting student learning and engagements as physical or hybrid laboratory courses.^{7,11} In addition, Son et al. showed that using both virtual and physical laboratory modules (i.e. hybrid model) in a general education biology class reduced costs, enabled increased student enrollment, and still improved student learning outcomes over virtual only or in-person only lab sections.¹¹ The overall goal was to design an undergraduate lab class that reflects some of the breadth of skills and concepts required in the biomechanics field in an online or hybrid format. The challenge remains as to how to provide a meaningful laboratory experience in biomechanics with low resource requirements that can be run in an online or hybrid manner for large classes. A potential solution to address this, in particular, during restrictions imposed by the COVID-19 pandemic, is described below.

Course Set Up

The main content focus for the course was hands-on experience with biomechanics covering materials testing and gait analysis. This scope was based on the expertise of the instructor, which is typical of biomechanics instruction,³ and student demographics, as none of the students had any experience with biomechanics laboratory techniques. The underlying goals of the course were to explore, with a focus on biome-

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chanics, the design of experiments, testing techniques, and comparisons of experimental data to theoretical calculations. These goals helped provide a rich, experiential experience for students to improve student engagement in the material and deepen student learning.² As with any course, the “value” of the expected work and skills presented needs to be made very clear to the students to improve student learning and engagement with the materials.² Content of the value of the skills that are presented can be made in the lectures, as small group discussions, homework assignments, or as part of the laboratory modules. This point is especially important for students that have not chosen biomechanics as their curricular pathway of study.

The course described covers an upper level, required, stand-alone biomechanics laboratory course. However, these laboratory modules could also be applied as a hands-on component to a parallel lecture course in biomechanics. For our course, all students attended weekly lectures on material related to the lab and were then split up into their lab sections. Previously, the lectures were taught in person, but these lectures will be taught online starting in Fall 2020 using Zoom in addition to using our course management system (Canvas). Small group work or discussions, which were conducted by students chatting with neighbors in the face to face setting, will be recast in “breakout rooms” (such as are available in Zoom). Small group work has been shown to foster greater student engagement and improve student outcomes.⁹ Both the instructor and TA can move through the breakout rooms to facilitate and answer questions. Students can share their screens and use the ‘white-board’ in Zoom to display work and annotate the presented page. The optional recitation period was run by the TAs to provide additional support on key topic areas and can be repeated in an online format.

The laboratory sections had lab teams set to three members, so that each member would have maximal exposure to the laboratory environment.⁹ The teams were created such that students with additional mechanics training are spread through the teams to provide opportunities of peer teaching of foundational mechanics.¹² Due to COVID-19 restrictions set by the university, we will have teams of 2 that will be present in the lab for Fall 2020 with a restriction on the number of students allowed to be present for any single section. Unfortunately, this is fewer students per team than has been shown to be optimal.⁹ In addition, we will not be able to “sprinkle” students with greater mechanics background in each team, where they act as peer teachers,^{12,4} as they make up only 10–15% of the class. So additional focus on mechanics fundamentals

and practice during the lectures will be needed to bring all students up to speed for the labs.

NOVEL INITIATIVES

Laboratories

The course has seven different laboratories run during a 15-week semester, where some labs can be run over multiple weeks. The lecture portion of the class provides all relevant foundational materials needed to support the laboratory work. Some of the lab modules were better suited for moving to an online environment than others and a list of recommended delivery methods for each lab are shown in Table 1. In-person laboratories were determined due to safety requirements and/or equipment needed to conduct the laboratories. As this is a higher-level laboratory in our department, the modules developed provide lab goals without a “cookbook” style procedure so that the students must develop the process for obtaining required data.¹⁰ All of these labs can be done in-person, of course, but options for conducting most of the labs in a home-setting are discussed for those students that may not be able to come in for class. Materials that are not commonly found in the home can be shipped to the students as needed. The order of the labs presented in Table 1 was the order that they were conducted during the last in-person offering of this course. However, the order can be altered as desired. Comments about which labs scaffold off previous labs are put in the descriptions, so some sequential order can be maintained.

Dissection Lab

The goal for the Dissection Lab is to teach appropriate and safe dissection techniques of biological samples that can then be used for future mechanical testing. The biological sample used were chicken wings, which are readily available. The dissection uses of scalpels to carefully section the specimen to collect needed samples of bone, complete muscle preparations and skin samples for use in later laboratory modules. Laboratory safety, specifically for the collection of potentially biohazardous samples, should be emphasized. This lab was not considered as an “online” option as liability constraints at our university restrict having students use scalpels in their homes without instructor supervision. Each student can be given his/her own specimen to dissect so team members can be spread out in the laboratory for social distancing with help available by other team members, instructor, and TA. The collected samples will be frozen until needed

TABLE 1. Laboratory modules with recommended method of delivery.

Laboratory	Mode of delivery
Dissection	In-person
Image analysis	Online
Particle tracking (video analysis)	Online
Gait analysis	Online
Beam bending—wheat-stone bridge circuit building	Online
Beam bending—testing	In-person
Axial loading	Online

for use in later laboratories. For a fully online version of the course, a video of the dissection by the instructor or TA can be created and presented to the students.

Image Analysis Lab

This lab introduces basic image analysis to students using Matlab and consisted of analysis of a series of grey-scale images. Any images can be used, but we used images of organoids created with two experimental methods. The student teams import images into Matlab and find geometric properties, such as centroids, areas, and circularity, of the organoids. From these calculations, the student teams determine which of two methods was most successful in creating organoids. Students will have to analyze and interpret data as part of their undergraduate careers, in line with ABET student outcome SO 6.¹ In addition, data analysis is a common bachelor's level task in many research and industrial environments and such is a universal skill that can be applied in the future.

Materials for this lab are easily distributed via course learning management (CLM) system and teams can work in breakout rooms in Zoom during their lab sections or “meet” outside of class as needed. The instructor and TAs will be available during laboratory time to respond to student questions and provide “Just in Time” feedback.⁷

Particle Tracking Lab

Particle tracking is used in many fields. Students can see this technique demonstrated in most professional sporting events. In bioengineering, point tracking is used in gait mechanics and cellular motion tracking, as examples to discuss with students. This laboratory also provides students an opportunity to work on designing an experiment that they will use to collect and analyze their own data. Through tracking the movement of “particles”, students determine the relationship between position, velocity, and acceleration of these particles by analyzing videos taken of moving objects. Materials for this lab consist of “particles”, Hexbugs

were used previously, but anything small that can move in a 2D plane can be used, such as marbles, toy cars, or coins for in-home experimentation. In addition, students use their cell phones for video capture and an in-plane scale, like rulers or measuring tape, for determination of the objects' positions. At most 2 objects are used for this lab with most of the work being done with only 1 object in the visual field unless students are skilled with programming. (Fig. 1) This lab builds directly from Imaging Lab in terms of Matlab coding skill needed to complete the analysis.

Gait Analysis

Gait analysis is a common biomechanical practice that is used widely in the field. The instructor can show videos from internet or virtual tours to show a working gait lab and discuss normal and pathological gait. Students can collect basic walking gait parameters for

FIGURE 1. Schematic of particle tracking experimental set up with two particles (blue and orange circles with tracks indicated with dashed lines) with scales for x and y axes. Particles are videoed from above (camera not shown).

analysis, for example stride width and stride length, using 6–8 feet of butcher paper, newspaper, or other craft paper and have the students use water or water-soluble ink on their feet (Fig. 2a). Materials for this lab can be sent to students in kits if needed for in-home experimentation. Students can vary walking speed to observe changes in gait parameters change with velocity. Team members can exchange data so that a larger data set can be used for analysis and interpretation of variations in gait parameters.

This lab can be combined to determine joint mechanics with additional equipment. Data are collected by placing markers or contrasting tape on a subject and videoing the subject walking (Fig. 2b). The cellphone or video camera would need to be positioned so that desired markers are in the viewing field and are in focus. Joint mechanics can be simplified to looking at joint angles at various phases of the gait cycle. Point tracking will be analyzed using Matlab. This lab builds from Particle Tracking Lab if using video or Image Analysis Lab if using still images taken from the video. It would be much easier for student to work in teams of at least 2 for this lab as the setup is more complex. Therefore, this additional component of the lab would be more conducive for a hybrid approach.

Beam Bending Lab—Wheat-Stone Bridge Circuit Building

Students apply their instrumentation foundational knowledge towards using uniaxial strain gauges that will be applied to the bone samples collected in the Dissection Lab. Students create the wiring diagrams and schematics for the wheat stone bridge circuits

(covered in prior course) that will be used to run the strain gauges. The building of the required circuits can be done at home with kits containing needed circuit building equipment, such as breadboards, wires, and resistors, sent to students. The circuits can be tested virtually using simulators, such as Simulink. Although this lab is not specifically related to biomechanics, asking students to recall prior knowledge has been shown to help reinforce and deepen learning.² In addition, students learn that the integration of different disciplines is necessary to complete certain projects.

Beam Bending Lab—Testing

This lab requires that students design the experiment and collect and analyze their data, which are compared to theoretical calculations. The lab uses bone samples collected in the Dissection Lab. The students are introduced to material testing of biological samples under bending. There are two parts to this lab: (1) application of strain gauges to bone samples and (2) testing of samples under bending loads. Displacement data from the strain gauge will be compared to the crosshead data so that the students can compare localized “point” displacements versus overall displacements. The application of the strain gauges could be conducted at home, if the materials are sent to the students, such as glue, sandpaper, etc., and detailed instructions on the application process as this can be difficult for those that have not done this previously. The students can use Zoom on their cellphones to show their work and get help from the instructor and TAs. The instrumented bone samples should be frozen if not tested immediately. As the testing portion of the lab requires the use of specialized testing equipment,

FIGURE 2. (a) Basic gait mechanic parameters measured from footprints on paper. (b) Monitoring joint mechanics using markers placed on appropriate joints and videoed.

such as a materials testing machine and power supplies to run the wheat-stone circuits, it needs to be done in-person. Students that are unable to attend the in-person portion of the lab can patch in via video for the testing and data can be sent to them for analysis and interpretation. The in-person teams can schedule specific times to do the testing to reduce student numbers in the lab. For fully online offerings, the instructor or TA can film the set up and testing of the bone samples with a second video of the force/displacement curves from the material testing machine. These videos with the mechanical data would be sent to students for further analysis.

Axial Loading

The students are introduced to materials testing using uniaxial loading on biological samples. This lab requires that students design the experiment and collect and analyze their data, which are compared to theoretical calculations. The lab uses skin and muscle samples collected in the Dissection Lab and rubber bands in uniaxial tensile loading. The lab setup uses low cost materials (clips, weights, student-owned cell phone) (Fig. 3) to add known loads to sample. The

markings on the sample (made with Sharpie markers) will be tracked using a camera or cell phone and the images analyzed in Matlab. This lab builds from Image Analysis and Particle Tracking Labs due to tracking of multiple points. This lab can also be used to monitor creep by videoing changes in the position due to load of the two markings over time if desired. For fully online offerings, the instructor or TA can film the set up and testing of the biological samples. This video or images with the mechanical data would be sent to students for further analysis.

If it is desired that students do some of the experimental work at home, material kits for the set up with rubber bands can be sent to the students. They can then compare their rubber band data to the biological data provided by the instructor. To reduce costs, the students can be required to return the kits after the lab module has been completed.

REFLECTION

Biomechanical testing techniques are varied and applicable to many situations. Presented here is an upper-level biomechanics laboratory class based on well-founded course design principles. Although actual hands-on testing has been shown to promote deeper learning of abstract concepts,¹⁰ the use of a hybrid model can be implemented to reduce contact and maintain course goals. These goals were to introduce techniques used in biomechanics, such as image and video analysis, design of experiments, and collection, analysis, and interpretation of experimental biomechanical data in comparison to theoretical mechanics. Prior studies have shown that hybrid laboratory courses can be very effective with regards to student learning and engagement, as long as, sufficient student support is provided.^{7,11}

There is a need to provide “value” in the material to students who have not chosen biomechanics as their curricular pathway to encourage greater student engagement and deepen student learning.² This includes the concepts of integrated course design⁶ to give opportunities of learning with low stakes assessments and frequent feedback. The main goal of this laboratory course is to give students the opportunity to learn a range of biomechanical techniques and concepts, with the hope that they gain insight into how such skills can benefit future careers. Emphasizing the value of each skill learned and how it can be applied to many aspects of bioengineering is important for students that have limited biomechanics background and should improve engagement with the material.⁶ The use of frequent assessments with homework assignments and quizzes ensured that the students get some practice in

FIGURE 3. Schematic for experimental set up for axial loading test. This would be provided to the students to aid with testing set up. Cell phone camera (not shown) should be placed in line and parallel to the sample with view of the graph paper for scale.

mechanics fundamentals.⁶ The recitation can give additional assistance to students that are having difficulty. Reinforcement offered in this course design, by using similar coding processes in multiple labs, helps students refine and build on prior work. The instructor can require that students in the team change roles so that they all learn the different skills, particularly coding. Changing of roles within the team also would help with assessment of teamwork (ABET SO 5),¹ if that is part of the course.

If there are cases where students cannot or are unwilling to come into the laboratory to perform the work in a face-to-face setting, team members can use cameras to do synchronous labs with input from the online students. Many aspects of these labs can be made into an online-only experience by providing data and videos of the experiments for data analysis and interpretation by the students. However, making this course entirely online without the hand-on experience would remove a vital experience that engineering students need and desire.¹⁰ Students “learn by doing” and troubleshooting their work, with the added value of taking on-paper calculations into actuality. This laboratory course was set up for students with only basic physics and calculus preparations so it can be offered from the sophomore to senior year. However, some testing techniques learned in this course could be of use during senior capstone and having this course earlier in the students’ academic careers would be more useful. Another alternative or value added to the student experience would be to have the students conduct simulations of the material testing labs (bending and axial loading) in Solidworks or a finite element analysis package, such as Ansys or Abacus. This step that can be implemented after the students perform hand calculations would provide greater depth of understanding how stresses and strains vary throughout the sample with loading. These simulations can be compared to experimental data, as well as, the hand calculations. Limitations would be similar in that students would not get the experience of building and testing their designs. In addition, the students will need time to learn the software in order to perform the calculations if they have not had experience in prior courses. This adds additional content to a potentially full schedule. However, being able to perform and interpret data from simulations is a valuable engineering skill that can be used in senior capstone projects as well as future careers.

Assessments will be conducted to ensure that hybrid and on-line only students are achieving course goals. Pre-lab assignments will ensure that all students are prepared for the labs and can be applied to all students

no matter if they come to the lab in-person or not. These pre-lab assignments will be presented through our CLM and be due prior to the lab section. The assignments can range from short, multiple-choice style quizzes to determine if the student has read the laboratory module to completing extensive laboratory theoretical calculations or simulations. Feedback from the instructor on the larger pre-lab assignments would require that be turned in early enough for responses to be generated. Concept test assessment questions⁸ will be added to lectures and to laboratory reports to determine the depth of understanding of the material between hybrid and online-only students.⁹ Lecture content can be adjusted based on the understanding presented by the students. In addition, in class “clicker” questions can be added to gauge individual student understanding of material with time for small group discussions of their answers before the instructor responds.^{2,9,12} Comparisons of these responses can be used to assess differences in learning for different methods of delivery when all other content is similar between the cohorts.

Presented in this manuscript are modifications to biomechanics laboratory modules so that they can be presented in a hybrid method with options for a fully online modality. Learning objectives for the course include the presentation and use of biomechanical skills such as image and video analysis, point tracking, mechanical testing, comparisons of theoretical and experimental data, experimental design, and gait analysis. These objectives can be experienced in online or hybrid formats. Hands-on exposure to the use biomechanical equipment can only be done with a hybrid format, although instructor-created videos can be used by students to get an overview of how these machines operate. Careful planning around the foundational knowledge brought in by the students can lead to an engaging and informative class. The skills learned in this lab can be used in future coursework, like senior capstone, and future careers in biomechanics and bioengineering.

CONFLICT OF INTEREST

The author declare that she has no conflict of interest.

AUTHOR CONTRIBUTIONS

The author contributed wholly and to every section of this manuscript.

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