Hands-on Biomechanics Lab for Undergraduate Universities

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***Abstract*—This paper discusses the development of a biomechanics lab course suitable for use at undergraduate engineering institutions who wish to expand their elective offerings or move towards developing a bioengineering degree program. The labs are designed to be low cost and feasible in a teaching environment with groups of students rotating through stationary lab setups. The biomechanics course at the University of Portland has nine labs. The six stationary labs are 1) Gait Force Profile Analysis, 2) Basketball Freethrow Arm Angle Analysis, 3) Biomechanical Arm Muscle Analysis, 4) Muscle Fatigue Analysis, 5) Occupational Biomechanics Glove Fatigue Analysis, and 6) Breathing, Heart Rate, and Knee Motion Analysis. The three labs performed as a class are 7) Sprint Acceleration and Terminal Velocity Analysis, 8) Auto Collision Analysis, and 9) Orthopaedic Implant Mechanical Testing. The remainder of this paper is a detailed description of each lab, its learning objectives, and how it was implemented. Other aspects, such as final projects, research reports, and student opinions of the course will also be discussed.**

Keywords- biomechanics, hands-on laboratory experiments, undergraduate engineering, bioengineering

I. Introduction

In recent years, undergraduate engineering programs across the country have seen marked increases in enrollment, with the enrollment increasing 15% between 2006 and 2009, bringing enrollments to the highest level since 1982 [1]. Mechanical engineering has seen the greatest increases, but bioengineering is rapidly growing in popularity, and it's no wonder, as the US Department of Labor and Statistics predicts a 72% growth in jobs between 2008 and 2018 in bioengineering fields [2]. Traditionally, bioengineering was only taught at the graduate degree level, but the last ten years has seen a tremendous increase in the number of undergraduate institutions offering bioengineering degrees. Developing a full-fledged bioengineering program is a long, involved process with multiple considerations that the institution must take into account, and yet students want to learn about bioengineering now, during their brief four year tenure. As educators, we have the opportunity to introduce students to the field of bioengineering through special courses and electives that will give them the exposure they need to pursue careers in this field. One such course is Biomechanics, which has been developed in the Mechanical Engineering program at the University of Portland (UP). This combination lecture and lab course is designed to expose students to the very broad field of biomechanics. The purpose of this article is to clearly outline the lab component of a course developed at UP and to provide enough detail that other undergraduate engineering programs could implement a biomechanics course in their curriculum at low cost.

The target audience for Biomechanics is engineering students who have taken Physics, Statics, and Dynamics. It is helpful if they have also taken Strength of Materials and some kind of lab in signal measurement, but not required. Most engineering students will not have taken any biological sciences, such as Biology, Physiology, or Anatomy. Students interested in the bioengineering field should be encouraged to take such courses to fulfill science requirements or as electives, as this will only improve their understanding of the field. Students will also not have had exposure to testing with human subjects and how to analyze data gathered from human subjects. Knowing these restrictions, the build-up of the course requires some foundational knowledge.

The course at UP is offered three days a week, with two hours of traditional lecture and one hour of lab. The syllabus covers several broad topics: Anatomy & Physiology, Biomechanics: Statics, Biomechanics: Kinematics (Dynamics), Lower Body Performance (Hips, Legs, & Knees), Muscle Tissue Mechanics, Bone Tissue Mechanics, Fatigue, Occupational Biomechanics, Sports Biomechanics, Accidents and Injuries (Vehicles, Consumer Product Failure, Slip & Fall), and Orthopaedics. These topics are all subjective, and any of them could be eliminated, replaced, or emphasized depending on the instructor. Also, some of the topics are covered through a combination of guest speakers from local industry and field trips. UP is located near a biomechanics research lab, a prosthetic upper limb manufacturer, an athletic shoe company, and an orthopaedic implant company. However, any local industry could be substituted that has some relativity to the field of biomechanics.

Laboratory experimentation is an important component of this course in biomechanics. Dealing with human subjects and the ability to gather meaningful data for analysis is one of the key challenges in biomechanics. Unlike other engineering disciplines, bioengineering is extremely dependent on test setup conditions. Thus, graduates need hands-on experience with research techniques in biomechanics, and how to present those results to an audience of their peers. Human performance is influenced by fitness, age, gender, diet, fatigue, prior activities, time of day, and countless other variables that cannot be controlled. Generated data is noisy and can be altered by placement of electrodes, movement of the body, clothes worn, stance, temperature of the room, air flow, etc., so it is very difficult to compare results from laboratory experimentation to published literature, as it is virtually impossible to recreate the same conditions. In order for students to be successful performing biomechanical research in their field, they need to have firsthand knowledge of the challenges and limitations so that they can properly interpret their results. The course at UP has eight to nine laboratory experiments. This number can be increased or decreased at other institutions as needed to fit the curriculum, and the exact types of experiments can also be adjusted as needed to give students the exposure desired. At UP, six of the labs are stationary, and the student groups rotate through them every two weeks. The first week is used to read about the lab and learning objectives and to practice with the data collection equipment. Technical journal articles on the subject of the lab station are posted online, and those are also read by the students prior to performing the lab. Many of the labs also require the student volunteer to wear particular clothing or shoes, so this gives the groups time to prepare for data gathering the second week. Three additional labs are performed outside of the classroom, and all groups participate in the lab at the same time. The six stationary labs are 1) Gait Force Profile Analysis, 2) Basketball Freethrow Arm Angle Analysis, 3) Biomechanical Arm Muscle Analysis, 4) Muscle Fatigue Analysis, 5) Occupational Biomechanics Glove Fatigue Analysis, and 6) Breathing, Heart Rate, and Knee Motion Analysis. The three labs performed as a class are 7) Sprint Acceleration and Terminal Velocity Analysis, 8) Auto Collision Analysis, and 9) Orthopaedic Implant Mechanical Testing.

First, it is important to emphasize that this is an introductory, broad overview biomechanics course developed for undergraduate mechanical engineering students. Since UP is a teaching institution, funding for the development of this course came from the School of Engineering and from an internally awarded Butine Grant. Funds were thus very limited, and state-of-the-art data gathering equipment was not the objective. Instead, low cost ways of gathering the type of data desired was purchased, and much of the instrumentation came from Vernier Software & Technology, a company that specializes in science education instrumentation [3]. Many other pieces of equipment are standard, commercial sports equipment, tools, and electronics. Concepts learned in this course, however, are easily transferrable to more sophisticated tools the students may encounter in the future. The total cost for all equipment used in this course was about $4000, purchased over a period of three years.

In this senior level course, students have already been exposed to numerous writing and presentation experiences, but they have not learned how to present their work in a format suitable for journal publication. As such, these laboratories are designed to give students skills in experimental design, hypothesis testing, and journal publication writing. At the beginning of the semester, each student performs a clinical literature review on a biomechanics topic of their choice, which they then submit in typical journal format, with Abstract, Introduction, Methods, Results, Conclusions, Discussion, and Works Cited. They must cite a minimum of five peer-reviewed references, using library resources to obtain the full articles. They summarize the articles and then analyze the similarities and differences between opinions and draw their own conclusions. This journal format is then used for all group laboratory reports.

At the end of this course, student teams conduct student-designed experiments on any area of biomechanics. Topics have ranged from baseball swing analyses to vehicle-pedestrian accident reconstruction analyses. Again, these reports are written as journal articles, and each team must present their findings to the class. This has led to lively discussions, and students really enjoy the opportunities to define their own experiments.

The remainder of this paper is a detailed description of each lab, its learning objectives, and how it was implemented at UP. As the goal was to provide a forum for students to become better experimental researchers, outcomes for the laboratories were not defined. Each lab station had a set of equipment and a handout. The handout gave an overview of how to use the equipment and the learning objectives of the lab. It then provided a series of open-ended questions to answer. Students could choose to answer one or more of the provided questions or create a hypothesis of their own. As each lab was conducted over a period of two weeks, the first week the students familiarized themselves with the provided equipment and decided as a group what their hypothesis would be. The second week, a student volunteer would arrive appropriately attired, bringing any necessary props or equipment, and the team would collect the data during the lab period. They then had one week to analyze their results and submit their journal-formatted report.

II. LAB EXPERIMENT DETAILS

A. Gait Force Profile Analysis

In this lab station, students gained an understanding of how shoes affect the motion of the foot. They were directed to walk and jog across a force platform in athletic shoes, rigid sole boots, and barefoot. They had a choice of collecting all the data for one foot or alternating feet. They were equipped with two force plates by Vernier Software & Technology. The force plates were connected to a Vernier LabPro interface. The LabPro was connected via a USB cord to a Windows XP computer. The software used to read the input was Vernier's LoggerPro for real time graphing and analysis. The two force plates were summed within LoggerPro and the output was exported for later spreadsheet analysis, using Microsoft Office Excel 2010. Like much of the equipment used in this course, the force plate has limitations. It can only gather force in the z-direction, perpendicular to the floor. This is a significant limitation, but a lot of good data can still be collected with this device. Three axis force platforms are very expensive and must be installed flush with the floor, which was not an option in the lab at UP. The Vernier force plate looks similar to a bathroom scale, and since it is not flush with the floor, early attempts to use it for walking force profiles were unsuccessful. First, the student volunteer had to step up onto the force plate and then back down. The step up motion altered their gait and made it difficult to compare changes in walking profile. Second, the force plate was small, and students had a hard time adjusting their stride to land their foot squarely on the force plate. To overcome these challenges, a ramp was built to allow a gradual change in inclination. The ramp was built wide enough for both feet, and two force plates were placed under a wood cover to give an extra long striking surface for running. This new ramp was student-built from plywood and was designed to be modular for easy storage when not in use.

Recently, barefoot running has become popular. Biomechanically, there are several advantages to barefoot running, especially the more natural gait. In an athletic shoe, a runner will stride out and strike heel first. This leads to larger forces in the knee joint and thus a higher probability of injuries. However, barefoot running is not necessarily the answer, as most runners now run on paved surfaces that are much harder than natural surfaces, and these surfaces are often strewn with sharp objects and fluids that could infect the foot. Thus, shoe manufacturers are now marketing so-called barefoot running shoes. The goal of the lab is to compare the walking and running force profiles with different footwear. Like all of the labs, the data gathered depends upon what the student group decides they want to analyze. For each lab station, a series of open-ended questions were asked to promote the students to think about what they should observe. These questions are based around the learning objectives of each lab. For this lab, the questions were: 1. How does the shape of the force profile change for shoe type? 2. How does the magnitude of the impact force change for shoe type? 3. How does the force profile change for running versus walking?

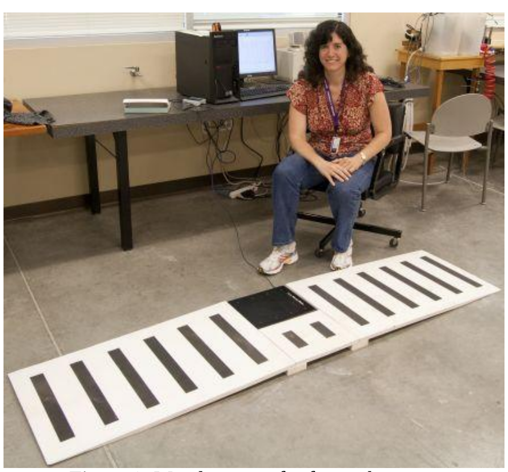

Figure 1: Wooden ramp for force plate

B. *Basketball Freethrow Arm Angle Analysis*

In this lab, students made a video recording of a volunteer shooting basketball freethrows. They were directed to capture the angle of the arm at ball release and to correlate this with the success or failure of the shot. The lab station was equipped with a Panasonic video camera with 40 gigabyte hard disk drive and a tripod. Within the lab, a standard basketball stand with a reduced rim height of seven feet is set up on its rolling base. The base is filled with water to counterbalance the weight of the stand. Part of the safety training for the lab explains the dangers of having a water-filled base. If a student were to hang from the rim, the stand would come over, and the mass of the water flowing towards the front of the base would accelerate that motion. The lab station also has a regulation size basketball and a ball pump. To facilitate finding the arm angle, the volunteer's shoulder, elbow and wrist are marked with black permanent marker. Within LoggerPro, video input can be analyzed LoggerPro has a video utility that advances the movie file frame by frame. Marks can be added at each frame and plotted as desired in real time. The students advance to the frame of ball release and mark each joint with X-Y coordinates and determine the vector between elbow and shoulder and elbow and wrist. Using the dot product, they can then calculate the included angle. The angle can be correlated with the success or failure of the shot, with most student groups recording "swish", "backboard make", "rim make", or "miss" for a total of 30 shots. Questions for this lab were: 1. How far off from ideal does this angle have to be to miss the basket? 2. What does the shot look like if the arm angle is oblique versus acute? 3. Is there a significant difference between a “swish” and a backboard shot in terms of arm or body profile? 4. Besides arm angle, what other factors influence the success of a basketball shot?

C. *Biomechanical Arm Muscle Analysis*

For this lab station, the students investigate mechanical advantage of muscle attachments using either a biomechanical arm or leg developed by Denoyer-Geppert [4] and a dual force sensor and low G accelerometer from Vernier Software & Technology. The biomechanical arm apparatus has attachment points that allow the biceps muscle to be simulated with the dual force sensor. Weights are placed in the hand of the biomechanical arm, which causes the arm to rotate downwards about the elbow joint. The tension in the biceps is adjusted until the forearm is once again horizontal. This is repeated for multiple weights in the hand and two different biceps muscle attachment points on the forearm. The sensors are attached to a Vernier LabQuest Mini unit, which is a simplified version of the LabPro, with four input/output ports. The LabQuest Mini is connected to a Lenovo Windows XP computer and the sensor input is analyzed using LoggerPro.

The goal of the lab is to demonstrate how human muscles act at a mechanical disadvantage in favor of increased range of motion. The LoggerPro software has many built-in mathematical functions, so the low G accelerometer signal can be integrated twice to get position, and this can be used to make the arm horizontal. Most student groups, however, simply use the protractor scale on the elbow joint to determine horizontal. The output result should show that at the nearer attachment point for the biceps muscle, the muscle is producing about eight times the force in the hand; whereas, at the further attachment point, the muscle is only producing about three times the force in the hand. The questions for this lab were: 1. What is the mechanical advantage (multiplying factor) for the far muscle attachment point versus the near muscle attachment point? 2. Why are muscles attached so closely to the joint? How does this influence the design of muscles and bones? 3. How could biomechanics of the arm be improved externally (with tools and sports equipment)?

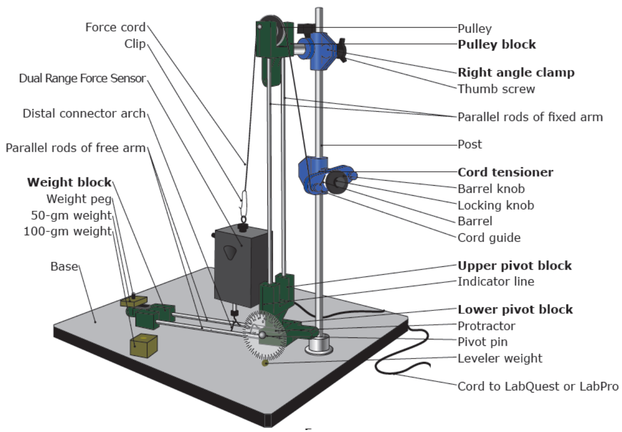

Figure 2: Denoyer-Geppert biomechanical arm [4]

D. Muscle Fatigue Analysis

This lab introduces the use of electromyographic signals (EMG) to capture electrical signal from muscles. EMG signal is extremely noisy and highly dependent on electrode placement, so the students get to learn what EMG signal can be used for and what it cannot. The volunteer performs three exercises, first wrist extensions with a light weight with electrodes on the forearm extensor muscles, then they flip their arm over and perform wrist flexions. The extensor muscles have baseline potential voltage noise, but they only "fire" when the wrist is extended. After gathering this data, the volunteer moves the electrodes to the biceps muscle and does biceps curls with the maximum amount of weight they can lift. These are repeated until the volunteer cannot produce any more repetitions, at which point their team begins cheering for them forcefully. With cheering, the volunteer finds they can do multiple additional repetitions. Throughout the exercise, the EMG signal changes, first decreasing in overall amplitude, then increasing in firing frequency. When cheered, the muscle EMG signal does not improve, allowing students to consider what is happening, such as other muscle recruitment. The questions for this lab were: 1. When the muscle is being activated versus not activated, how does the EMG signal differ? 2. How does placement of the electrode affect the EMG signal? In other words, what can you infer and not infer about the muscle based on the signal amplitude? 3. How does EMG amplitude change with fatigue? 4. How does cheering (brain stimulus) affect performance? 5. What is happening to the EMG amplitude when the volunteer is fatigued yet being cheered on to perform more reps? What is happening biomechanically in the muscles?

E. Occupational Biomechanics Glove Fatigue Analysis

Many professions require the use of gloves, which protect hands from the elements and harsh conditions, but also decrease feedback on grip force. Thus, workers must increase their grip force when wearing gloves, and this accelerates fatigue. For this lab station, the students are provided a Vernier hand dynamometer, a LabQuest Mini unit, a Windows XP computer, and a variety of work gloves. They first grip the dynamometer barehanded and record their maximum voluntary contraction (MVC). Then they record the amount of time they can hold within 75-80% of their MVC barehanded. Then, they don a glove and try to hold 75-80% of their MVC for as long as possible. This is repeated for both hands for all gloves, as well as for pinch force. The students are surprised to see the effect of gloves on their performance. They are also surprised that pinch force is improved by wearing gloves. The questions for this lab were: 1. How do gloves affect grip and pinch forces? 2. From an occupational biomechanics viewpoint, what are the advantages and/or disadvantages of using gloves for various tasks? 3. How could the effects of gloves be minimized? In other words, for a particular task that requires a certain type of glove, how should the glove be designed to minimize fatigue?

F. Breathing, Heart Rate, and Knee Motion Analysis

For this lab, a student volunteer rides a stationary bike for 30 minutes then stopping for 5 minutes while breathing into a Vernier spirometer and wearing a heart rate chest strap or wristwatch. The respiration rate and heart rate are recorded frequently for the first few minutes, then every minute for the remaining time, then frequently again during the rest period at the end. The goal is to determine whether heart rate or respiration increases first and which one decreases first. In the future, the hope is add a carbon dioxide sensor to the spirometer to see the oxygen flow rate.

Also for this lab, the students video record a few pedal rotations of the knee and import the motion into LoggerPro for analysis. Both the angular velocity versus time and the angular velocity versus angular position are analyzed to show the interesting kinematics of the knee. The questions for this lab were: 1. What do the knee path profiles look like during cycling? Why is this significant? 2. How do heart rate and respiration rate change during exercise? Which increases first? Do they reach steady state over time? Which decreases first? 3. How do revolutions per minute and “aerobic threshold” affect heart rate and respiration? 4. How do seat position and body posture appear to affect the biomechanics of motion, heart rate and position?

G. Sprint Acceleration and Terminal Velocity Analysis

For this lab, an indoor or outdoor running space is needed where the student volunteers can safely run 100m without having to slow down at the end of their sprint. Timers with stopwatches are located at each 10m interval, and everyone starts their stopwatch at the same moment. Using an inexpensive high speed camera from Casio, video of the start is captured at frame rates up to 1000 frames per second, although 30 frames per second is sufficient. Each volunteer runs two trials, and the results are averaged. The goal is to demonstrate that terminal velocity is not as significant as acceleration rate and time in determining a person's finishing sprint time. Thus, a "fast" runner is one that accelerates to full speed in the shortest period of time. No questions were provided for this lab.

H. Auto Collision Analysis

For this lab, UP has constructed two buggies that ride on rails. The buggies were built from garden wagons and modified to have windshields and rail wheels. They have child booster seats on them and shoulder harness seatbelts from a salvage yard. In the seats are two large teddy bears. Students push the two vehicles toward each other over a distance of 30 feet, then release them just prior to impact. A high speed video camera is used to capture the release and impact for analysis of deceleration of the passengers. The vehicles are inspected for damage, and sheared bolts are located and dent depths are measured. The experiment is then repeated without the seatbelts. This experiment has evolved over the years to something that can be done precisely and indoors. In a lecture on accident reconstruction, forces on the body due to automobile collisions is discussed and physics is used to determine impact forces. In the future, it is hoped that the teddy bears and vehicle could be outfitted with accelerometers to capture additional data, but the G forces are too high for the sensors currently owned. No questions were provided for this lab, as it was intended that all groups would determine the speed of the two buggies, their impact force, and anecdotally discuss the effects of the seatbelts. Due to delays in the fabrication of the rails for the buggies, there was not enough time to write reports before the end of the semester, so this lab was discussed by the class as a group. Slow motion videos were played on the digital projector, and students discussed the pros and cons of how the data could be analyzed.

I. Orthopaedic Implant Mechanical Testing

One major field in biomechanics in orthopaedic implants. These implants must survive at least ten million cycles of wear testing, at physiologic worst case loads. There are dozens of standards for how the tests must be performed. One test that can be performed is on the spine. Spinal fusion surgeries are performed hundreds of thousands of times per year in the United States. On the posterior spine, four pedicle screws are fastened to adjacent vertebrae, and then rods or plates are positioned over two screws on adjacent vertebrae and anchored in place. This constructed can then be mechanically tested using a fatigue test machine, or more simply with strain gages on the hardware in a standard tensile test machine. For this lab, a sheep spine double loin is purchased from a local butcher. Using scalpel blades, all the excess tissue is removed and disposed of in a compost bin. Using a standard cordless drill, hardware donated by an orthopaedic spine company is installed on the sheep spine, and it is mounted in the test stand to gather some data. This is an easy lab to do, especially if no testing is performed. Much biomechanical testing is done on animals and cadavers, so exposure to the process of dissection is a valuable skill. Performing "surgery" on the spine also helps the students learn, as many will end up being present during surgical procedures, either to learn more about the challenges of current devices or to test a device they have designed. This year's class did not get to prepare the spines themselves, and testing was only discussed with the class as a whole, as it was conducted late one evening in order to finish it by the end of the semester. New dynamic fatigue test equipment and better planning will allow this lab to be more hands-on in future years.

III. Conclusions

Implementing a biomechanics course at an undergraduate university is a feasible option for engineering programs that would like to offer electives, tracks, or majors in the bioengineering field. This paper has outlined how such a course with a full laboratory experience was developed at the University of Portland at very low cost. Other educators have discussed the importance of teaching experimental design at the undergraduate level, specifically in the area of biomechanics [5-9]. Gefen provides a list of equipment available to students in his undergraduate course, along with guidelines for using the equipment. Like the course at UP, he avoids providing "recipes" for the students to follow. He also places students in groups of three to four and has them conduct literature reviews prior to each laboratory. They are required to prepare a protocol in advance of the lab, which is then approved. For his course, there are six lab topics: tissue mechanics, biomaterials, posture, gait, heart valve, and exercise biomechanics. UP offers a separate course in biomaterials, so only four of the six labs are similar. Gonzalez works at a university that built a laboratory equipped with modern research equipment, specifically for the use of undergraduates for education and research [6]. Again, the equipment is meant as "tools" for students to answer their own research hypotheses. The goal of Gonzalez is to teach students to observe phenomena, formulate a hypothesis, develop an experimental methodology, and gather data for analysis. Results are presented as a poster or conference proceeding paper. He states that experimental methods are as important as analysis and design in the engineering curriculum, and agrees that biomechanical labs should be the focus of the course, not a supplement to lectures, if we hope students to develop skills in independent scientific inquiry. His laboratory is equipped with very high quality equipment, such as a 5 camera motion analysis system and a six degree of freedom force plate. His setup requires extensive software as well, which makes the cost of such a laboratory well beyond the means of smaller, teaching universities. His course has three defined topics and two independent design experiences. The three topics are maximum vertical jump analysis, hand dynamometer output with EMG, and arm stiffness measurements. The independent experiments are designed by the students, conducted in the laboratory, and then presented. He notes that several of these independent experiments have led to undergraduate research investigations. Cluss describes a low-cost method to measure the biomechanical forces in a moving human body [7]. She uses a 2D video analysis and software from Vernier, Inc. called VIDEOPOINT to evaluate the vertical jump of ballet dancers. With the software, students and calculate the center of mass of the various body parts and deduce the accelerations and thus forces in the joints. She states that many state-of-the-art video analysis systems cost upwards of $250,000, but with a simple video camera, or even a cell phone with video function, and some low-cost 2D software, meaningful results can be obtained. This compares well with the experiences at UP. Using regular and high speed cameras (purchased for less than $300), we are able to analyze many complex motions, including basketball freethrows, sprinting acceleration, golf swings, baseball swings, and simulated auto collisions. With software, it is simple to determine the acceleration and velocity, from which many parameters can be calculated, depending upon the hypothesized question. Zapanta also discusses the importance of laboratory courses in bioengineering and how his university has developed an introductory course to cover the five areas of biomedical engineering offered at his institution: cellular and molecular biotechnology, bioinstrumentation, bioimaging, biomaterials, and biomechanics. He uses EKG to study the heart and EMG to study force generation by limbs for movement. For the EMG labs, he has two experiments. The first is fatigue of the bicep muscles, using a weight held stationary in the hand for 60 seconds. The Fast Fourier Transform is analyzed. The second EMG lab is done in conjunction with a force plate to study the phases of jumping. This is analyzed using MatLab. His course also includes a research project, which culminates in a poster presentation with a written report. Student feedback is very positive for his course, and students liked the breadth of coverage. Some complained that the MatLab was too hard, and some students wanted more depth. At UP, MatLab is covered in a one credit hour computer science course, so all students have excellent MatLab skills, but the Vernier LoggerPro software is quite comprehensive, so no students have used MatLab to complete their analyses. Barr discusses a series of virtual labs developed by VaNTH that evaluate student outcomes based on pre and post tests and surveys administered to the students [9-10]. These biomechanics lab modules cover a variety of topics, including Iron Cross muscle strength, various gait analysis exercises (center of gravity, force generation, and EMG of quadricep muscles), jump height experiments, and the performance of the ACL during knee extensions. Although the data is provided to the students, the modules are quite thorough and provide a series of videos, relevant literature, and analysis tools to the students. If implementing a physical lab experience is not feasible, this may be another low-cost option for some universities. The course is broad enough to cover a wide variety of biomechanics topics, while still having plenty of depth for students to understand how and where these concepts could be applied.

For the course at UP, student evaluations have been overwhelmingly positive. The overall score was 4.73 out of 5. When asked what students liked best about the course, comments included, "The labs were really interesting and fun.... It is nice that we can infer what we find most interesting from the labs and have some freedom to do them as we want. I learned about new programs and ways of analyzing which I liked as well." Also, "This course is a great opportunity for those looking to go into biomedical engineering. It really gives a well-rounded opportunity to learn about every aspect of biomechanics. The material learned could be used in many different ways. The labs were also a great experience.... The reports helped the students really look into the background of what they were doing and then really how to evaluate the data they just collected."

Based on this feedback, the open format of the course and lab exercises will not be changed, but students were disappointed that we did not get to do the orthopaedic dissection and testing as planned. This summer, UP is receiving a dynamic fatigue test machine, which will provide a much-needed testing resource for biomechanical experimentation. Labs based around this new test machine are planned for the upcoming year. Also, Gefen's requirement of a test protocol in advance of data collection is intriguing and will be tried [5]. Gonzalez's formal approach to scientific inquiry was similarly intriguing, and I intend to add a stronger emphasis on development of the experimental method [6]. And Zapanta's use of Fast Fourier Transfer and MatLab to further analyze results are excellent low-cost options for UP that I intend to incorporate into the set of skills I provide to the students [8].

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