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Development of Low-Cost, Hands-On Lab Experiments for an Online Mechanics of Materials Course

Dr. Jamie Douglas, University of Wisconsin Colleges

Jamie Douglas is an Assistant Professor with the University of Wisconsin Colleges Online and at the University of Wisconsin – Fox Valley. She completed a bachelor's in civil/environmental engineering from the University of Illinois (UIUC) in 1998 and a Ph.D. in civil engineering from the University of Wisconsin – Madison in 2007. She currently lives in Appleton, WI with her husband and two children.

Dr. Mark H Holdhusen, University of Wisconsin, Marathon County

Mark Holdhusen is an Associate Professor of Engineering at the University of Wisconsin, Marathon County. He began at UWMC in Jan. 2005 after completing his Ph.D. in mechanical engineering at the Georgia Institute of Technology. Holdhusen received a bachelor's in mechanical engineering from the University of Minnesota in August of 1999. He currently lives in Wausau, Wis., with his wife (Elona), son (Milo), and daughter (Odelia).

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Abstract

Online education has expanded quickly in recent years and offering an engineering curriculum online has been limited by the ability to replicate lab experiments that are integral to some courses. Some approaches to lab experiments in distance education or online courses have been attempted including recording video of lab experiments or creating simulations of laboratory experiments that run virtually via the internet. This paper outlines the development of a set of inexpensive, transportable lab experiments for students in a Mechanics of Materials course offered via distance education. The set of labs were developed to allow for hands-on learning with a kit of supplies and a list of experiments that students could perform at home using readily available materials. The labs were developed using materials that had properties which mimicked the behavior of traditional materials like steel or aluminum, but exhibited those behaviors at much lower applied loads and stresses. Most labs allowed for actual data to be taken and analyzed while a few labs qualitatively demonstrated the concept. These labs were initially integrated into an existing Mechanics of Materials course offered via both audiographics and will be offered in conjunction with an online course in a coming semester. An assessment was given to determine how comfortable students were with laboratory concepts before and after the course. In addition, feedback was solicited after each lab to get feedback from students about implementation of the lab and its helpfulness in understanding mechanics of materials topics.

Introduction

Engineering education is increasingly moving to nontraditional delivery modes, especially online delivery. During the fall of 2009, over 5.6 million students were enrolled in at least one online course, a 21% increase over the previous year.[1] As online education expands it is increasingly important to ensure the quality of instruction is at least equivalent to that offered via traditional methods. In the online environment it is not only difficult to present complex engineering concepts, but it is a huge challenge to offer any experimental laboratory experiences. This paper reports on the development of a set of low-cost, hands-on lab experiments that can be performed at home as a part of an online mechanics of materials course.

There are four widely-accepted methods to deliver laboratory experience to online students: virtual simulations, on-site labs, simple home-based labs, and remotely accessed labs.[2] Little has been published regarding online labs for a mechanics of materials course. Bhargava et al. used virtual labs to deliver a laboratory experience to mechanics of materials students.[3] Alexander and Smelser used a combination of several lab delivery methods to deliver a distance mechanics of materials lab.[4] The approach taken in this paper was heavily geared towards simple home-based lab experiments.

This paper begins with background information as to why the course and labs were developed online for the University of Wisconsin Colleges. The outline of the course associated with the labs is then discussed followed by the details of the labs. Student and instructor feedback are then presented. Finally, some conclusions and future work are discussed.

Background

The University of Wisconsin Colleges (UWC) are part of the University of Wisconsin System. The UW Colleges are composed of 13 two-year campuses geographically dispersed across the state of Wisconsin. The Colleges mission is to prepare students for success at the baccalaureate level of education. The UW Colleges offer the first two years of general education including calculus, chemistry, and physics as well as introductory engineering courses and the engineering mechanics courses. The curriculum is offered via face-to-face instruction at five of the campuses and via distance education (DE) to the other campuses. Prior to 2007, the DE courses were offered synchronously using either audiographics or compressed video. Audiographics connects students via a telephone conferencing system and a web meeting using Blackboard Collaborate. The faculty member controls the computer and the meeting in real time. Compressed video is a teleconferencing system where the faculty member can connect via video to up to five remote campuses. Both methods require students to attend class at a specified time and day. The students must be physically present at their campus to attend the course.

The UW Colleges recently joined with the University of Wisconsin – Platteville (UWP) to offer a collaborative engineering program. In this program, the UW Colleges offer the lower-level courses for an engineering degree and UW Platteville offers the upper-level engineering major courses. The program would target place-bound students unable to attend engineering classes at UWP by using online streaming video to deliver the necessary content. In response to this collaboration, the UWC faculty determined that the current course offerings would need to be developed for an asynchronous online delivery mode. Over the last four years the faculty have migrated all of the UWC engineering courses to the online environment. This paper discusses the development of lab experiments that can be done at home as a part of an online mechanics of materials course.

The mechanics of materials course considered in this paper is part of the typical undergraduate engineering mechanics sequence including statics, dynamics, and mechanics of materials. Topics covered include stress, strain, axial loads, torsion, bending, transverse shear, transformations, beam deflection, and buckling. A requirement of the UW Platteville mechanics of materials course is a lab component. The course had been previously offered at the UW Colleges both with and without a lab component depending on the resources at each campus. Given the collaboration with UWP, the UW Colleges needed to offer the course with a lab via online delivery. Several options for the lab were discussed including a mobile lab travelling the state, bringing students to a central lab a few times each semester, and virtual online labs. Ultimately it was decided to create inexpensive lab experiments students could perform at their home.

The initial offerings of the mechanics of materials lab developed for online delivery lab was actually a part of the existing audiographics course. These students were located at several campuses across Wisconsin and did not have access to any other labs. Previously, the course was offered via audiographics with no lab component and students were expected to take the lab portion of the course after the transferred. For the first offerings of these at-home labs, students were given the labs and asked for feedback on the experiments. The following section outlines the lab experiment created for the course.

Lab Experiments

There were a total of 10 labs initially developed for the course; most of which consisted of three primary components. The first component was direct measurement of physical properties, where students would use their measurements and apply the concepts and equations from the lecture to perform calculations and derive physical meaning. Secondly, the calculated values could be compared with published values for that material property; or the measurements could be compared with the predictions from theoretical equations. The final component for some labs included observation and/or demonstration portions where students were observing or predicting the effects of a behavior, without making measurements or calculations about it. Students were encouraged to watch videos of similar experiments being performed in a materials testing lab, however, these labs were not based upon data collected during a simulated lab. Table 1 lists the lab experiments and which components were utilized for each.

Table 1: Lab experiments with utilized components

Lab Title	Practical Measurement and Calculations	Comparison to Published / Theoretical Values	Demonstration / Observation of properties w/o direct measurement
Error Analysis	X		
Allowable Stress	X		
Tension	X	X	X
Creep	X		
Shear Modulus / Thermal Expansion	X	X	X
Stress Concentration			X
Angle of Twist	X	X	
Cantilever Beam Deflection	X	X	
Simply Supported Beam Deflection	X	X	
Buckling / Strain			X

During the first year, students were required to purchase a $29 lab kit directly, and the second year students were charged a $55 course fee along with their tuition for lab supplies. Each student then received a lab kit in the mail. Note that there was some cost savings the first year due to extra materials remaining from the initial lab development. The kit included setup materials for the majority of lab experiments. However students were required to develop their own weight system, measurement tools, and provide some testing samples. A list of materials supplied with the kit and materials purchased or supplied by the student are listed in Table 2. Note that some materials were intentionally left out of the kits for two primary reasons. First, the cost of shipping some supplies without damage far outweighed the cost to purchase comparable supplies at a local hardware store (e.g. a ¼-inch dowel rod). Second, students might own or have free access to a more expensive piece of equipment, such as a digital caliper. Therefore it was considered a better option to keep costs down and have students buy those components only if they were not able to secure them elsewhere.

Table 2: Lab Kit Components

Supplied by Instructor with Kit	Separately Supplied by Student
Balsa wood set-up for allowable stress	Digital Calipers
Two 4-inch dowel rods	Weights (water, coins, etc)
Twelve inch length of copper wire	Double-sided tape
Nine inch length electrical cable	Aluminum foil
Eight inch length 60/40 tin/lead solder	Rubber Band
Shear modulus polyfoam and basswood setup	Hair dryer
Paraffin wax block	¼ inch dowel rods for torsion test
Two small clamps	Bending and deflection samples
Two sliding-glass door, ball bearing rollers	
Two U-bolts	
One pulley sheave with affixed set screw	

The following sections describe each lab experiment including the objectives and basic setup of the experiment.

Lab 1: Error Analysis

The first lab considered experimental error analysis. The objective was to understand the fundamental types of errors and to learn how to properly account for errors in measurements and calculations. In this lab, students were introduced to an overview of how errors occur, how they can propagate, and how they are measured in the lab. This was a critical initial lab since the subsequent experiments have a high degree of variability. Students learned how to account for errors in equations and how to estimate errors in their work. Students then applied error analysis techniques to evaluate variability in the thickness, diameter, and volume of a set of 30 pennies. The materials used for this lab were supplied by the students and included a digital caliper and 30 pennies.

Lab 2: Allowable Stress

The objectives of the second lab were to test the allowable shear stress in a simple connection and to analyze normal strain in a multi-component cable. In the allowable stress experiment, students used a simple double lap connection (provided in the lab kits and shown in Figure 1) made of balsa wood to measure allowable shear stress. Students added an adhesive (such as double sided tape) to the Part B illustrated in Figure 1, and then suspended increasing weight to get to failure. In this lab, as well as many other labs, students were required to fashion a hanger system and determine a means to accurately determine force (by weight). The example was given to use a known volume of water which has a predictable density to determine the weight. Students were also required to photograph and describe their individual setups as well as analyze the errors that might be introduced with their individual systems.

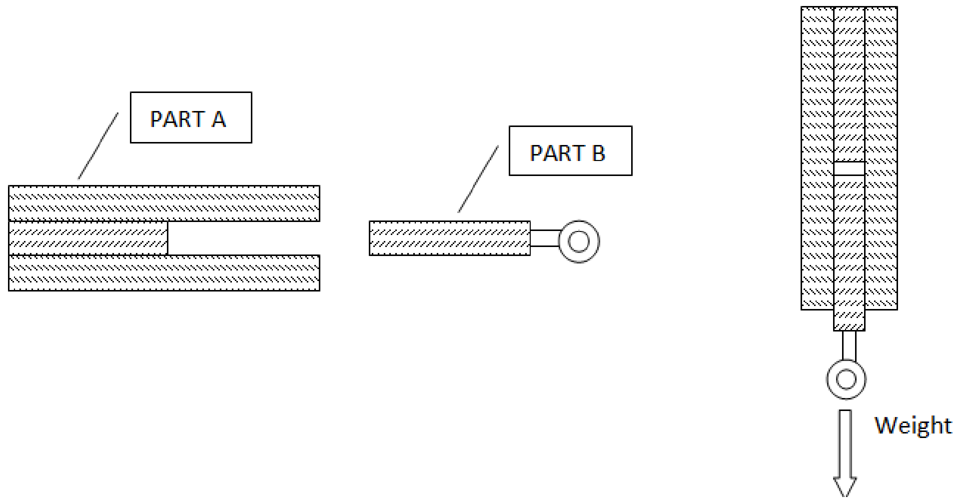

Figure 1: Setup for allowable shear stress experiment

The allowable stress lab also included an exercise adapted from *"Real Life Examples in Mechanics of Solids."*[5] Students were given a composite electrical cord and asked to dissect it and describe the various components and materials. Students then performed differential strain calculations based on hypothetical conditions placed on a similar, theoretical composite cable.

Lab 3: Tension

In this lab students performed a tensile test on copper wire at home and plotted a stress-strain curve. Students also performed a simulated tensile test on a steel bar. In the first part of the lab students performed a simple tensile test on a thin copper wire (Figure 2). As in the allowable stress lab, students were required to devise their own system of weights to test the tensile strength of the thin copper wire provided in their testing kits. They marked the gauge length of the wire and used a caliper to measure the strain. Students created a plot of the stress-strain curve for their measurements.

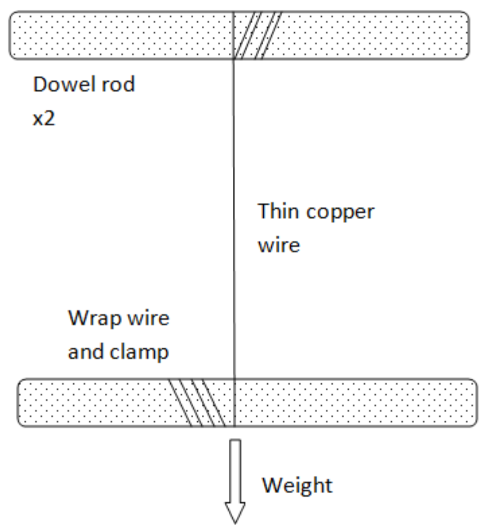

Figure 2: Setup for copper wire tension experiment

For the second part of the lab students performed a simulation and analyzed the results of a tensile test on a steel bar using a web-based java applet no longer available. They also watched a video of a tensile test being performed in a full-scale laboratory experiment.

Lab 4: Creep

In Lab 4 students observed and collected data on creep. Students were provided with an 8-inch length of 60/40 tin-lead solder, the type typically used for stained glass applications. Students hung a full gallon jug of water from the end of the solder and measured the increase in length over time. This lab was primarily an exercise in observation – with students taking measurements and creating a graph over time. Students were asked to observe the changes in appearance of the sample, and to hypothesize on the effects of temperature on their experimental conditions.

Lab 5: Shear Modulus / Thermal Expansion

In this lab students determined the shear modulus of a craft foam sample and explored the effects of temperature on expansion and creep. The setup for the shear modulus experiment included a piece of high density poly-craft foam sandwiched between two pieces of basswood (setup provided in the lab kit and shown in Figure 3). Students used their weight system to create increasing force on the free-floating smaller piece of wood and then measure the angle created within the foam due to the applied shear force. Students calculated the shear modulus, G, for the foam and compared their value with those obtained by other students in the class.

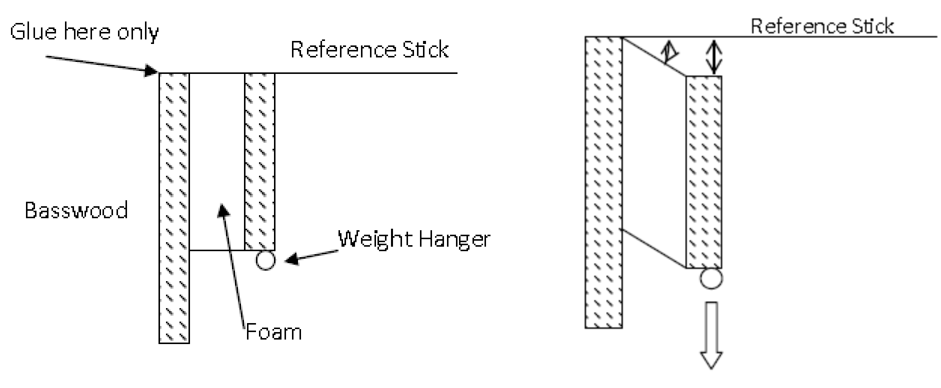

Figure 3: Setup for shear modulus experiment

The second portion of the lab considered thermal expansion. It included the measurements of length, width and height of a supplied block of paraffin wax at room temperature and after being placed in a freezer for 24 hours. Paraffin wax was chosen due to its high thermal expansion coefficient and the fact that it is a solid at room temperature. Students were able to compare their calculated coefficients with published values for paraffin wax.

A second thermal experiment was also conducted where students suspended a weight on a rubber band and then heat the rubber band with a hair dryer. Though no calculations were performed in this demonstration, students were asked to reflect on their hypothesis from the previous experiment on creep and consider the design implications with different materials that undergo temperature fluctuations.

Lab 6: Stress Concentration

In Lab 6 students explored the effects of shape on the concentration of stresses. This lab was largely a demonstration and observation experiment. Students were given two templates and asked to use those templates to cut out standard shapes (dog-bone and square-edge) of aluminum foil. Using the same hanging setup as the copper wire tension experiment, students suspended weights until the foil ripped and then compare the maximum stress for each shape. Students were then challenged to test shapes of their own design and compare them with the two extremes provided by the templates.

Lab 7: Angle of Twist

In this lab students explored the effects of torsion on angle of twist. This was the most complex experimental setup contained in the lab kit. The torsion experiment shown in Figures 4 and 5 included two sliding glass door rollers (with ball bearings) held to a wood board by U-bolts and aligned to pass a dowel or quarter-inch steel bar between them. In the middle of the two bearings, a three-inch pulley sheave was attached to the dowel and affixed with a set screw. This allowed the dowel to turn with the pulley, but rotate freely within the bearings. The other free end of the dowel was then fixed in a block of wood to prevent rotation. Students were provided with the two bearings, u-bolts, pulley sheave with attached set-screw. Students were then responsible for constructing the torsion setup and performing the experiment. In the experiment, students hung weights from the pulley creating a torque on the dowel. The angle of twist was measured using either a protractor directly or a ruler to find the change in arc length of the pulley. The data was plotted and the shear modulus, G, was calculated. Students were asked to repeat the experiment with a different material or the same material at a different length.

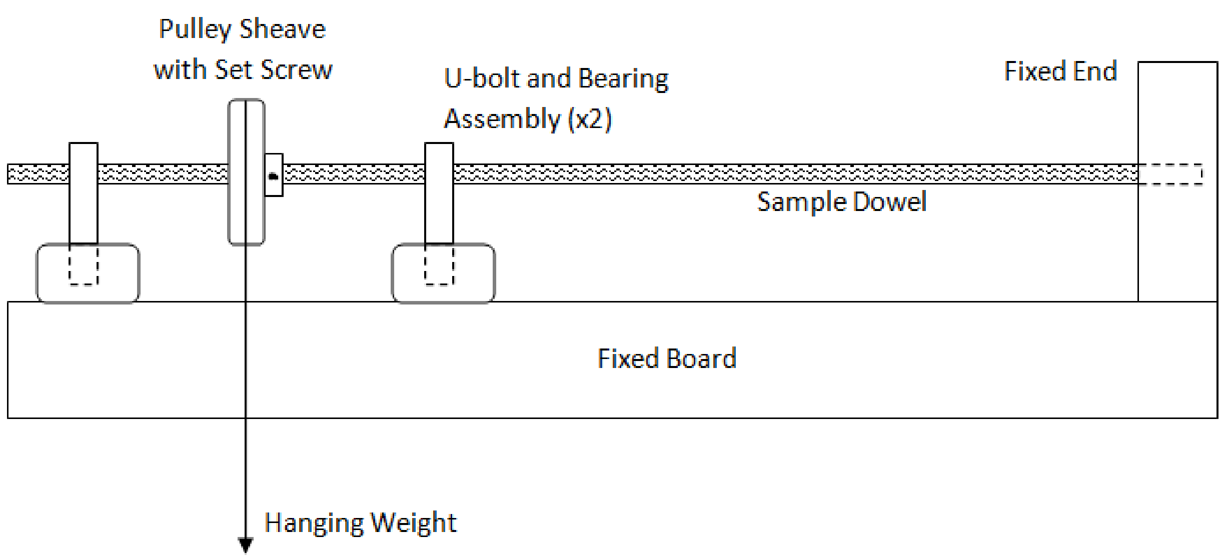

Figure 4: Setup of angle of twist experiment

Figure 5: Student submitted photos of angle of twist experiment

<u>Lab 8: Deflection of a Cantilever Beam</u>

Students predicted and observed beam bending in Lab 8. They were asked to choose three materials from home and fix them at one end to create a cantilevered beam. Students calculated the moment of inertia for each beam and obtained the Young's modulus from the internet. Students were asked to predict the displacement of the free end of the beam based on applied force. Students hung weight at the unsupported end of their "beams" and measured the deflection. Students compared their measured results with their predicted results.

<u>Lab 9: Deflection of a Simply Supported Beam</u>

The objective of this lab was to predict and observe the deflection of a simply supported beam. Similarly to the beam bending experiment, students were asked to collect three materials from home to test. Students created a simply supported beam by placing the beam between two supports without flexing them as shown in Figure 5. Students then used theory to predict deflection based on known or estimated properties of the materials. Weights were then hung from the center of each beam and the deflection measured and compared with the theoretical results.

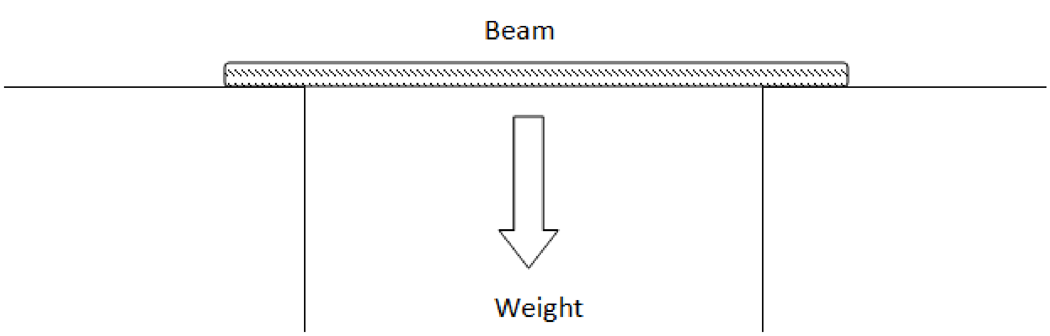

Figure 6: Simply supported beam for deflection experiment

Lab 10: Buckling and/or Pressure Vessels

The final lab's objectives were to perform a thought experiment, apply creative thinking skills, and apply knowledge of materials science applications. In this experiment, students were asked to design an experiment with commonly available materials to test a principle of either buckling or stress/strain transformation. Students designed experiments, created a drawing of the hypothetical setup, and then wrote out the experimental procedures and explained the theory it was designed to test. This lab served as a culmination of the lab course and a chance to apply skills learned to new and creative circumstances.

Assessment

The mechanics of materials course with the home-based labs was offered in the fall of 2011 and the fall of 2012 to a distance education class. The class consisted of 13 students the first year and 12 the second year. Each student was given a lab kit containing most of the necessary materials needed to perform the experiments. They would need to acquire any other materials necessary to complete the labs such as a caliper and a mass scale. The following section outlines some comments and assessment results from these students regarding the labs as well as some thoughts from the instructor of the lab component of the course.

In both courses, written comments were solicited from students regarding the labs. In fall 2012, students also completed an online survey, which solicited their responses to questions on learning gains using a 6-point likert scale. In both classes, approximately seven students chose to participate in providing feedback on the labs. Therefore it is difficult to draw conclusive results, but the preliminary findings will be used to refine the labs and future assessments as online students are added.

Written comments from the students regarding the labs were mixed. Many students stated the labs were a success in that they helped reinforce the concepts taught in the lecture. One student stated, "…at the start of class I was a little concerned how well it would work out doing the labs at home. In reality, I found the labs to be doable, interesting, and a positive learning experience." Students also noted that the labs explored how the theory could be applied. One student wrote, "They went right along with the lectures. They were great for showing real life applications." Another positive outcome students reiterated was that designing and building the experiments was enjoyable. The word "fun" was used by several students in assessing the lab experience.

Of course, there were negative comments from the students as well. Many students suggested not having accurate weights made the labs difficult and frustrating. The instructor suggested using water as a source of loading in the experiments as the density of water is known and the volume can easily be measured. However, students believed this did not give good results. One student that invested in an inexpensive weight set said, "Using water for weight is annoying and really limits you on where you can do the labs. Investing in an inexpensive weight really makes the labs more enjoyable." Another theme in negative comments was about the added cost of the lab equipment. Requiring the purchase of some of the equipment like a scale or caliper was seen as a bit excessive to several students. One student stated, "[For] lab courses on the campus, any student expects that the materials are already made available…but paying for a lab class and paying for the materials just took too much [from] the students."

In the online assessment in fall 2012, students were asked to rate their learning gains in three primary areas: understanding, skills, attitudes, and integration of learning across disciplines. Given the small sample of students, there were not a large number of conclusions that could be drawn from the data. However, a few areas proved to have interesting findings.

In the area of understanding the concepts, students were given a list of course topics and asked to rate their learning grains in each area on a scale from 1 (not applicable) to 6 (a great deal). For most concepts, student understanding ranged from 5.4 to 5.9, with the exception of column buckling, which was 3.7 out of 6. Notably, buckling was the concept which did not have a corresponding lab.

Additionally, when asked questions about the application on concepts, students felt confident in their understanding. When asked the question "I understand why studying mechanics of materials in important for engineers," students scored it at a 5.1; and when asked "I understand how studying mechanics of materials helps people address real world issues," students scored a 5.0.

While the demonstration of concepts learned in lecture was helpful to students, the lab skills gained were slightly lower. Students rated their ability to find errors in measurements at 4.7, and their ability to write discipline-appropriate documents (e.g. lab reports) at 4.7. The students did feel that they were able to predict the behavior of a material in the lab (5.6), but less able to choose a better material (4.9) or shape (5.0) for the job.

The instructor of the course felt that the labs were overall a success. Students were able to complete the assignments, seemed to enjoy the assignments, and did a good job of extending their experimental observations to new applications. Development of the labs created several challenges, including selecting materials that were low cost, but exhibited the desired behavior. It proved especially difficult to create a torsion setup that could be replicated at home with minimal friction interference. However, the resulting setup worked very well and student results were positive. Finding a balance between the included components of the lab kit and the cost of the kit will be an ongoing challenge.

Conclusions

The purpose of this project was to create a set of at-home laboratory experiments to compliment a mechanics of materials course taught through distance education (asynchronous online and synchronous audiographic courses). The challenges of developing the laboratory kits included selection of materials, inclusion of robust content, and minimizing the student cost.

The outcome of the initial offering of the lab course was successful, with students gaining proficiency with measurement, calculations, and applications of the theoretical lecture content. Student feedback was mixed, with many students both enjoying the labs and expressing positive learning from them. Some challenges remain, such as accurate home weight systems and maintaining a low out-of-pocket cost.

Future work on this project includes additional assessment to quantify student learning gains over the course of the semester, and work to address the ongoing challenges described above. Also, the labs must be implemented to the online delivery of the course. The online mechanics of materials course is currently being developed and the first offering, including these labs, will occur in an upcoming semester.

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