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A low-cost materials laboratory sequence for remote instruction that supports student agency

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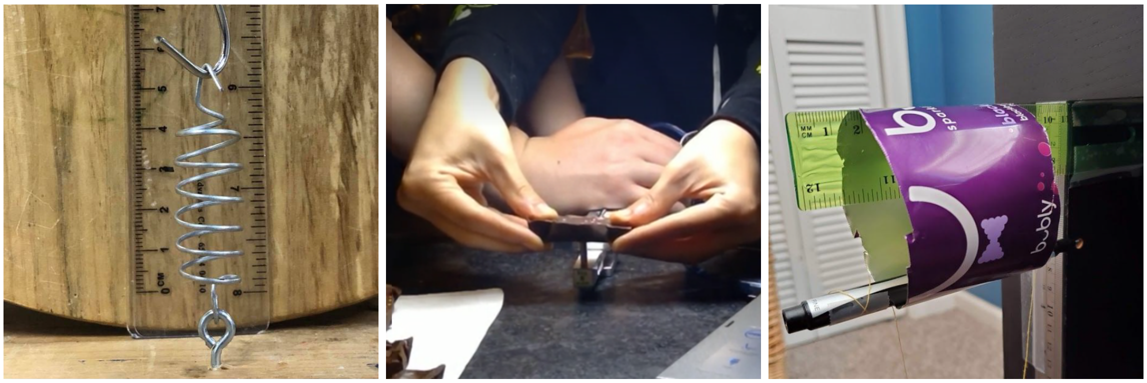
Under the new ABET accreditation framework, students are expected to demonstrate “an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions” [1]. Traditional, recipe-based labs provide few opportunities for students to engage in realistic experimental design, and recent research has cast doubt on their pedagogical benefit [2]. At the same time, the COVID-19 pandemic has forced institutions to move to remote learning. To address these challenges we developed a series of online labs for an upper-division mechanics of materials course.

Summer 2020 labs. In Summer 2020, low-cost kits were mailed to students with basic measurement equipment including a force gauge and a ruler, as well as two material specimens and other assorted hardware. The first lab activity consisted of a video demonstration of a traditional lab experiment with synchronous group discussions and data analysis. In the second lab activity, students performed a uniaxial tension test and a constant-load creep test on a length of nylon filament provided in their kit. Although the basic experiment was described in the activity, students were responsible for choosing some experimental parameters like the loading method and number of measurements to record. In the third lab activity, students designed their own experiment to measure the Young’s modulus of a provided steel wire that was much too stiff to test in uniaxial tension with household materials. Both the second and third lab activity were completed in teams. In addition to the activities, students created peer-teaching videos in which they demonstrated an ASTM (or other common standardized) test related to fracture. Examples of student-designed experiments from Summer 2020 are shown in Figs. 1a and 1b.

Fall 2020 labs. Some of the kits mailed in Summer 2020 arrived late, had to be forwarded to a new address for a student who moved, or failed to arrive entirely (for one student overseas). These difficulties were manageable with only 22 students, but were deemed a major concern for the fall semester. The lab activities were redesigned to be completed with only household materials. Furthermore, by this time campus reactivation made it easier for staff to access lab facilities and record demonstration videos.

The first three labs consisted of video demonstrations of traditional lab experiments with synchronous group discussions and data analysis. Two of these “traditional” virtual labs were supplemented with peer-teaching video activities. The final lab was a guided-inquiry activity focused on experimental design. Using only materials available at home, students measured the Young’s modulus of aluminum and used their results to design a hypothetical product. In order to provide the same opportunity for students around the world, the test specimen was taken from an



(a) (b) (c)

Figure 1: Examples of student-designed experiments: **(a)** The steel deformed into a coil spring. **(b)** Still from a video demonstration of a “fracture test” on a piece of chocolate. **(c)** Diametral tension test on an aluminum can.

aluminum beverage can. An example of a student-designed experiment from Fall 2020 is shown in Fig. 1c.

One measure of whether or not an activity supports student agency is the diversity of solutions generated by students [3]. We analyzed 36 reports from the final guided-inquiry lab and coded the experimental procedure on five key decisions such as the type of experiment performed, specimen geometry, and measurement method. We identified 29 unique approaches to the problem, with no one approach accounting for more than three submissions.

Analysis of student outcomes. Student outcomes were measured by a survey of students' attitudes and self-efficacy administered directly after every lab activity except for the first one. The fraction of students endorsing statements related to a sense of agency increased dramatically between the “traditional” labs and the guided-inquiry lab: from 52% to 82% for goal-setting and from about 64% to 92% for choice of methods. Self-efficacy increased significantly in the primary targeted skills (designing experiments, making predictions, and generating further questions), but there was no significant shift in skills not explicitly targeted by the guided-inquiry lab (equitable sharing of labor, expressing opinions in a group, and interpreting graphs). Overall, our experience demonstrates that at-home lab activities can achieve sophisticated learning outcomes without the use of lab equipment or expensive standardized kits.

References

[1] ABET, “2019-2020 Criteria for Accrediting Engineering Programs,” 2018.

[2] N. G. Holmes, J. Olsen, J. L. Thomas, and C. E. Wieman, “Value added or misattributed? A multi-institution study on the educational benefit of labs for reinforcing physics content,” *Physical Review Physics Education Research*, vol. 13, no. 1, pp. 1–12, 2017. _eprint: 1705.03580.

[3] S. Willner-Giwerc, K. B. Wendell, C. B. Rogers, E. E. Danahy, and I. Stuopis, “Solution diversity in engineering computing final projects,” in *ASEE Annual Conference and Exposition, Conference Proceedings*, vol. 2020-June, 2020.