Session

Adapting Engineering Laboratories to Enhance Learning using Real-Time Sensors

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Abstract

Clemson's NSF-sponsored EXPerimental Engineering in Real-Time (EXPERT) project is designed to assess the efficacy of using real-time sensors connected to laptops in engineering classes. Earlier papers described the painstaking procedure used to develop parallel laboratories—one set of laboratories using sensors and another set of laboratories not using sensors, both with the same educational objectives and approaches. This rigorous approach is needed to isolate the effect of using the sensors.

By studying the use of sensors only in laboratories that can be conducted with or without sensors, we constrain the benefits of this new technology. This paper will address the benefits of adapting the laboratory content and pedagogy to make the best use of the technology without limiting the use of sensors to only laboratories that could be conducted without them. This approach results in learning that cannot be compared experimentally to a control group because of the presence of confounding variables. Nonetheless, benefits to learning are discussed, including the reflections of students.

Introduction

Our previous work described the pedagogical approaches used in these curriculum materials and how those approaches were used in both sensor and non-sensor versions of the laboratories to isolate the benefit of using the sensors in the classroom.[1] The pedagogical equivalency of the sensor and non-sensor versions is an assumption that underpins the research design.[2] This paper focuses on updates to one of the parallel (sensor / non-sensor) laboratories, the development of a new parallel laboratory, and the extension of what we have learned about using the sensors in the classroom to exercises that cannot be designed as parallel laboratories because they cannot be conducted without the use of real-time sensors.

Ongoing laboratory development

Three lab modules are presented in the remainder of this paper. Each laboratory features a pre-lab activity in which students speculate as to what will happen or background material on the laboratory and questions for the students to answer. Each laboratory also has a post-lab activity in which students synthesize the "big picture," sometimes integrating other course material to better understand the laboratory.

The first lab module is an update of the cantilever beam laboratory published previously. The second lab module is the newly developed fluid mixing laboratory that is developed in sensor

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and non-sensor versions. The third lab module presented is a significant departure from those that can be developed in a parallel format. Some of the greatest gains of new classroom technology may be found in activities that cannot be reproduced without the technology. A book chapter is in press that discusses much more extensively the expectations and evaluation of technology in the classroom.[3]

Beam stiffness laboratory

This laboratory allows students to continue their investigation of stiffness using force and motion sensors begun with the springs laboratory described in our earlier work. After confirming that the cantilever exhibits the same proportionate response to increases in applied load, students determine the effect of modulus, length, width, and depth on the stiffness of the cantilever beam.

In an effort to use the sensors to their full advantage, this laboratory has undergone a significant modification that permits monitoring deflection *while varying the length of the cantilever beam continuously*. This new feature significantly improves the pedagogical value of the sensor version. The non-sensor version requires discrete measurements. The length of the beam is measured using a rotary motion sensor. By counting revolutions of the wheel (and knowing its diameter), the length of beam is displayed automatically by DataStudio, the software that collects data from the Pasco sensors. Using this configuration offers an opportunity to discuss data transformations with the students.

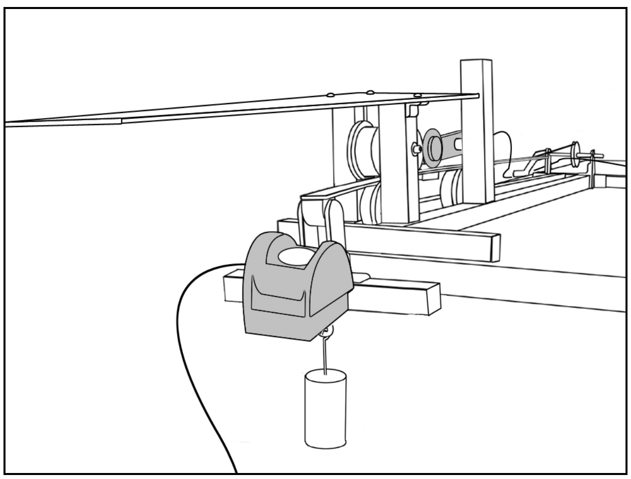

Figure 1. Adjustable cantilever apparatus.

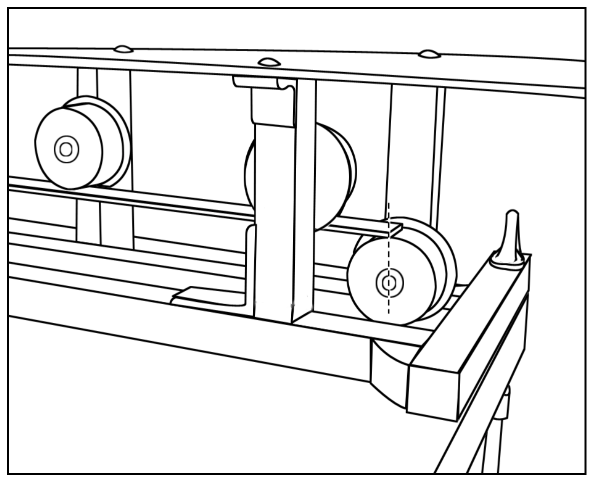

Figure 2. Zeroing the length sensor.

Since the stiffness of the beam is proportional to the length cubed, this experiment is very sensitive to any offset in measuring the beam's length. The laboratory protocol therefore requires that students zero the sensor when the loading point is directly above the support.

Figure 3 shows a graph of the data collected in this laboratory. Students collect data as they adjust the length of the beam and watch this graph develop. If the students have conducted the experiment properly, the exponent will be a good approximation of the correct value of three. More importantly, it is immediately obvious that this is not a linear relationship.

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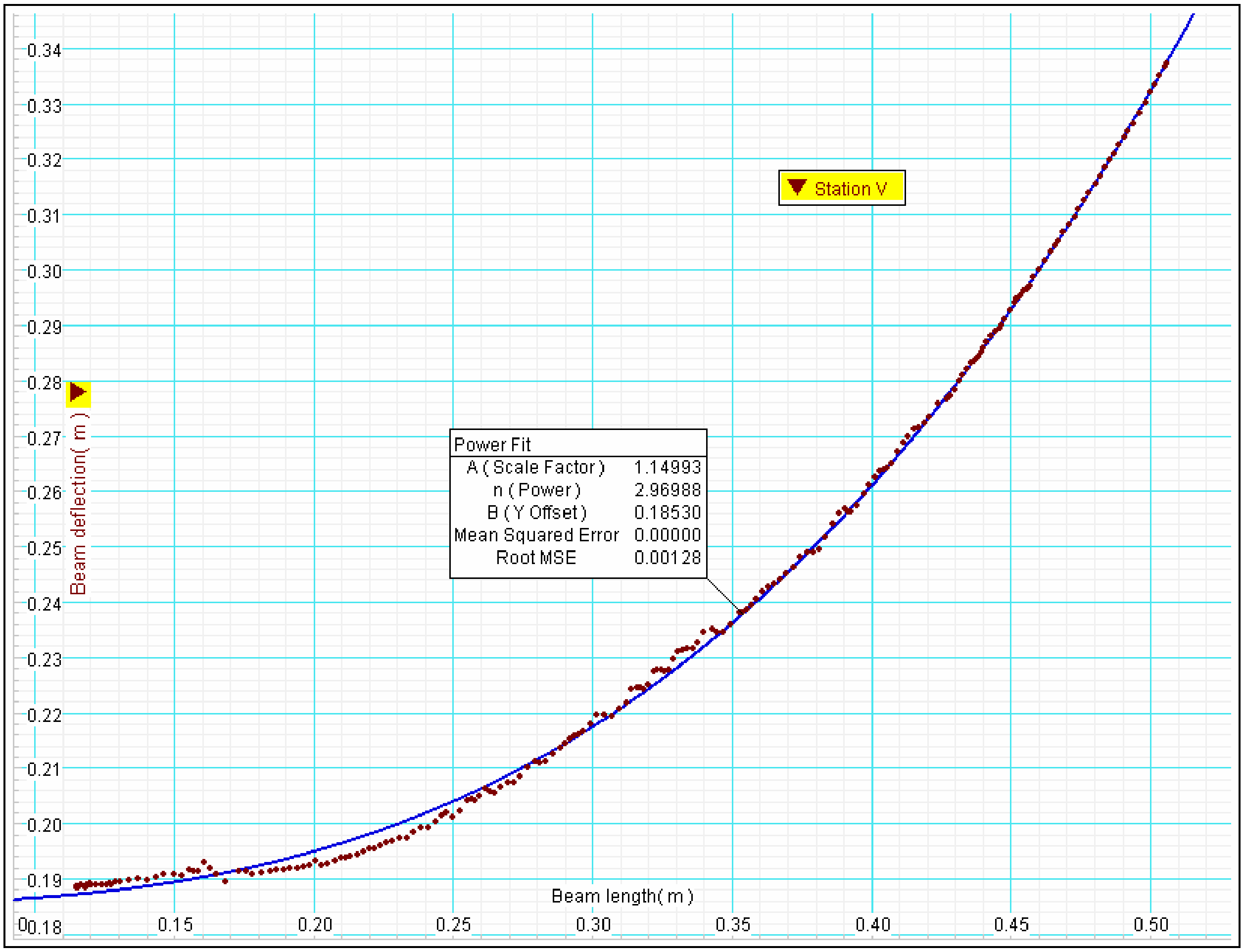

Figure 3. Original data and power fit of the effect of beam length on beam deflection.

Pre/post test data were collected for classes conducting this laboratory and a parallel laboratory that could not permit continuous variation of the beam length, but rather required the measurement of deflection at discrete beam lengths. Test results are not yet available.

Fluid mixing laboratory

In this laboratory, students examine the change in temperature of a fluid mixture as cold water mixes into hot water. The weight of the fluid mixture is measured, but is easily related to the mass or volume (or fraction of each) of the cold water in the mixture. This experiment allows students to identify another type of relationship. Since the temperature of the hot water is reduced by the addition of cold water, the temperature is inversely proportional to the weight of the mixture. We have reported earlier the study of exponential cooling curves, and this lab is designed to help students recognize that not all asymptotic curves are exponential. The example is particularly useful since this experiment also involves a cooling fluid, yet the choice of mixture weight as the independent variable (rather than time in the case of the exponential cooling curve example) results in a completely different relationship.

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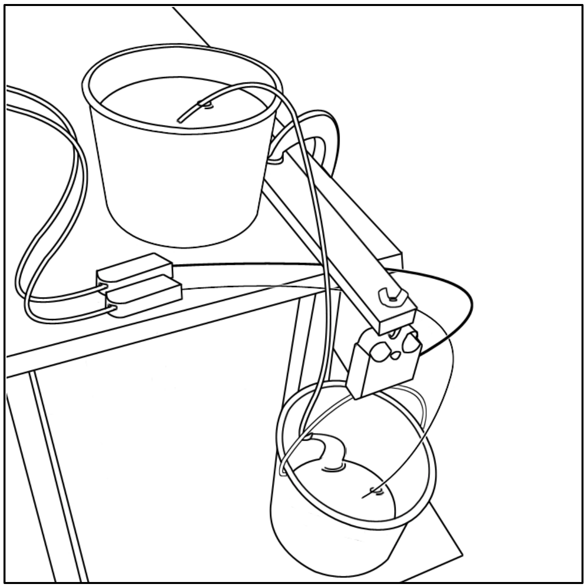

Figure 4. Fluid mixing apparatus.

Students compare the exponent and leading constant determined with those of an equation they have developed. Students use other measured values to calculate the starting temperature of the cold water and compare it with the measured value. Figure 4 shows the fluid mixing apparatus. Cold water flows through a siphon from the upper bucket into the lower one (initially containing hot water). Students start taking data just before the siphon is activated. Figure 5 shows a graph of a set of student data, demonstrating an excellent fit. In addition to studying the theoretical relationship, students recognize this as an inverse relationship (rather than exponential) because computing the temperature of a mixture of zero mass is nonsense, whereas exponentials have a definite value at the origin.

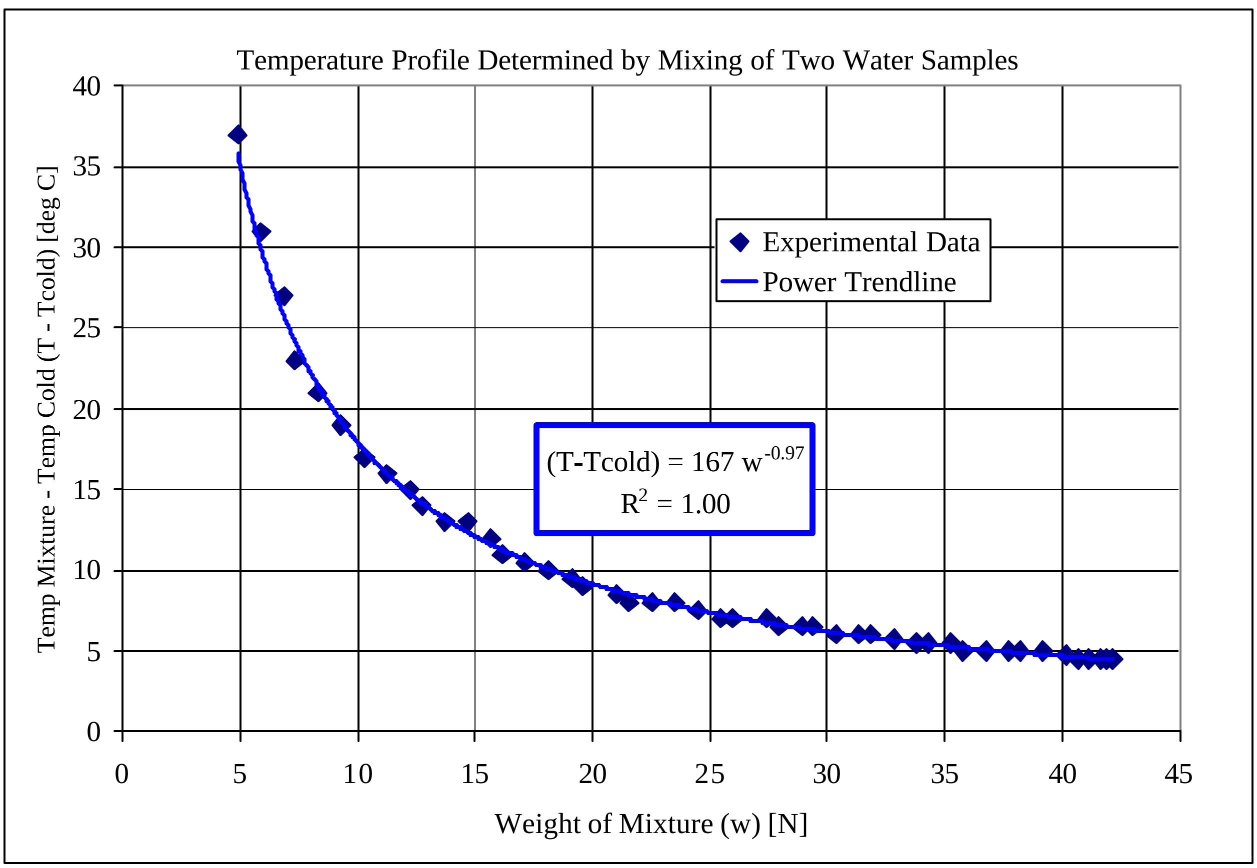

Figure 5. Studying the inverse relationship of the cold water added and the mixture temperature.

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Force Distribution laboratory

This laboratory tracks the progress of a ball rolling across a channel with a motion sensor as two force sensors record how the weight of the ball is distributed between the channel's supports. In the first procedure, students discover a simple linear relationship as the weight of the ball is transferred from one support of a simple beam to the other using the apparatus shown in Figure 6. Importantly, students note that the total force on both sensors is always the same—no matter where the ball is, the force sensors support its weight (no more, no less).

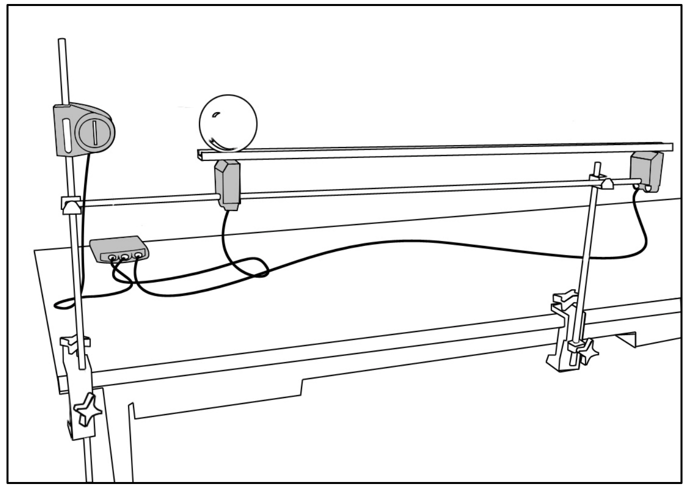

Figure 6. Set-up for Simple Beam Procedure

Using this example in which there are only vertical forces allows students to practice their understanding of $S F_y = 0$ without complication from lateral forces. The motion of the ball allows the evaluation of many individual static experiments. This highlights the role of statics as a special case of dynamics, which is important in preventing students from developing misconceptions that will influence their learning of dynamics. Stief and Dollár[4] note that "limiting statics to rigid, unmoving bodies hampers student learning." We agree with them that "a number of aspects of statics … are better understood with reference to motion." Each position of the ball represents a static example because, even if the ball is accelerating along the channel (as it will if the channel is inclined), the ball is not accelerating in the vertical axis of the force sensor. This helps the students understand the orthogonality of different motions.

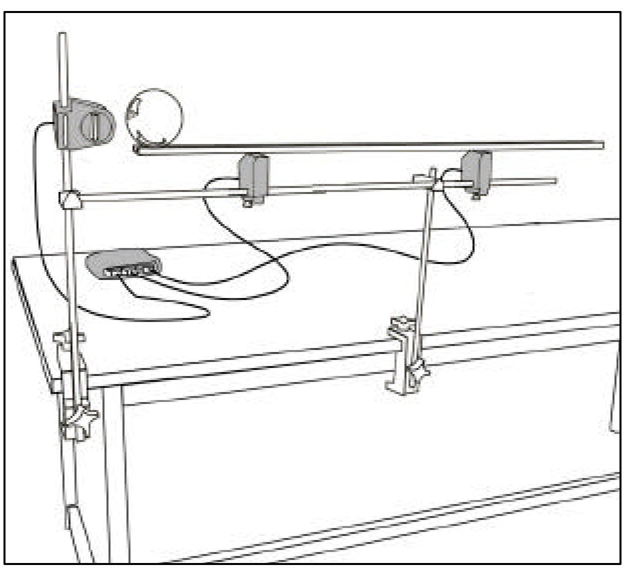

Figure 7. Setup for Double-Overhang

Figure 7 shows how the apparatus is changed in order to examine how the force distribution changes when the beam has an overhang at both ends. The relationship is still linear, but the overhang allows uplift to be generated at one sensor while the other sensor carries more than the weight of the ball to offset the moment of the overhanging ball. Still, even though an individual force sensor might support more than the weight of the ball, the sum of the readings of the two force sensors is still equal to the weight of the ball.

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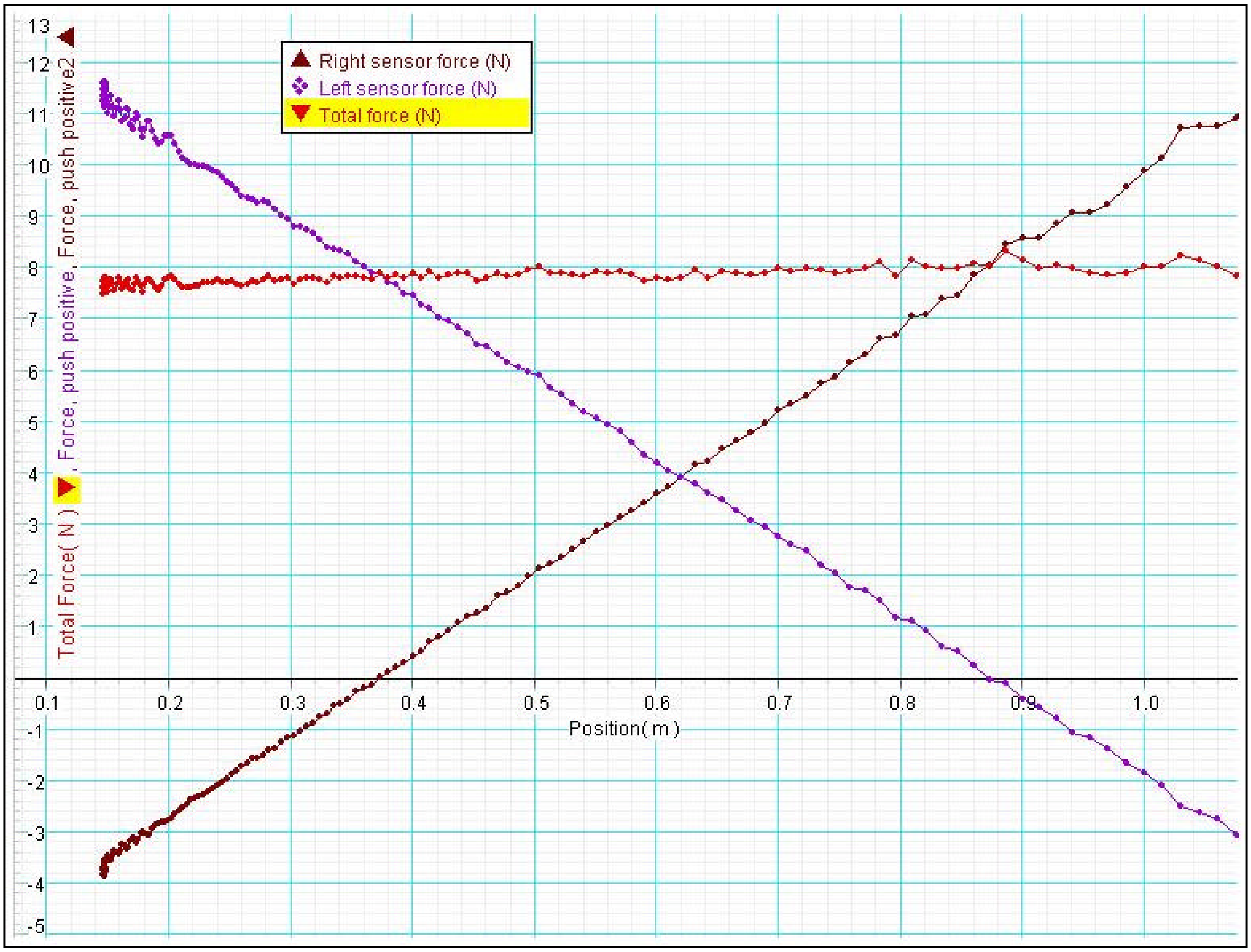

Figure 8. Left force, right force, and total force for double overhang configuration in Figure 7.

The remainder of the lab features experiments that are based on the geometry of a diving board, which allows the study of non-symmetrical effects. A sketch of a diving board with an adjustable fulcrum is shown in Figure 9. This is a useful example because the problem has context for most students.

The diving board model is used to investigate the effect of the position of the diver (the ball), the effect of the weight of the diver (keeping the diver's position constant), and the effect of adjusting the fulcrum position (as can be done on some diving boards). The setup used to study the effect of the weight of the diver is shown below in Figure 10.

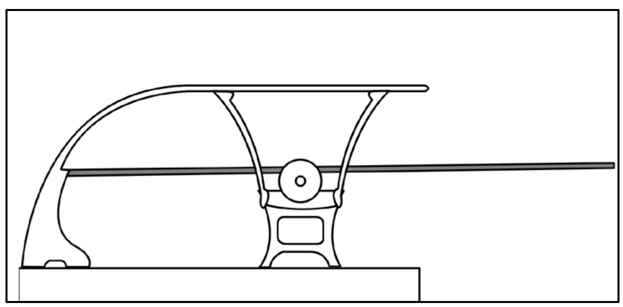
Figure 9. Schematic of a Diving Board with Adjustable Fulcrum.

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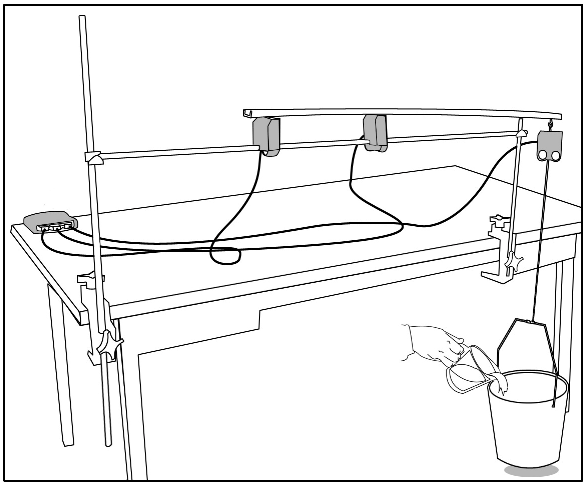

Figure 10. Investigating the effect of tip weight in diving board configuration.

Again, this problem is technically a dynamic problem. The force applied to the tip of the channel varies with time. Nevertheless, the force increase will be steady enough that we are not likely to see any interference in the measurement of the forces experienced by the left sensor (the "hinge" support" and the right sensor (the "fulcrum" support). As a result, we are able to relate the applied force (the diver weight, independent variable) to the hinge and fulcrum forces (dependent variables) without studying the time dependence. Note that the location of the applied force is constant in this experiment, so the motion sensor is not used.

Student predictions of the hinge and fulcrum forces as a function of the position of the ball in the double overhang setup of Figure 7 will be used as a pre-test of student understanding of force distribution after the simple beam experiments. Using the setup in Figure 11, students return to an experiment similar to the earlier beam geometries with two fixed supports and a moving load. In spite of asymmetrical geometry, the hinge and fulcrum forces still change linearly with ball position. Many students will predict a non-linear relationship in this case. A greater number of students misconceive that a significant change will occur as the ball passes over the fulcrum.

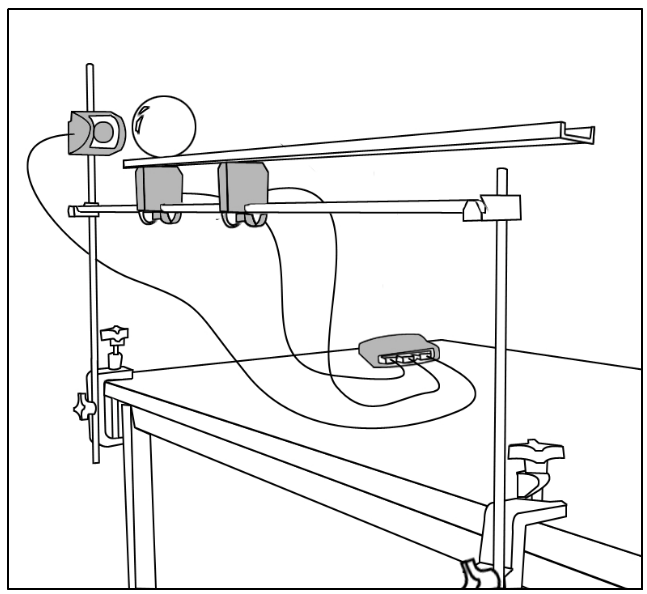

Figure 11. Studying the effect of position.

Student predictions of the hinge and fulcrum forces as a function of the position of the ball in the setup shown in Figure 11 will be collected as a post-test. In between the pre- and post-test, students will reflect on their pre-test predictions in light of their measured data and class discussion. After students run the experiment shown in Figure 11, students will again reflect on the differences between their predictions and their results.

As a follow-on assignment, students will be challenged to predict the effect of fulcrum position on the hinge and fulcrum forces as the fulcrum moves (theoretically) from the end of the board toward the hinge. Figure 12 shows these forces as a function of the distance between fulcrum and hinge. While this still requires a sum of moments to solve, it results in an inverse square relationship, which is interesting for the students to study.

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We are considering developing this laboratory experiment further by analyzing the acceleration of the ball. Since the motion sensor is able to report acceleration data directly, we are considering having students compare the rotational moment of inertia of different types of balls.

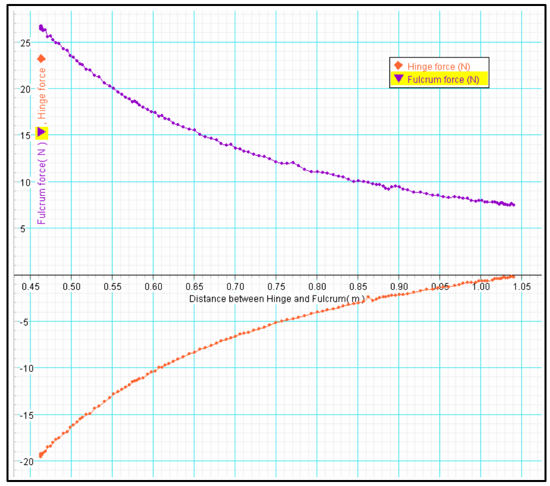

Figure 12. The relationship of hinge / fulcrum force and fulcrum distance.

A student reflects on our introductory activity

Students develop a facility with DataStudio and these sensors in two simple activities. First, students move hand away from and toward a motion sensor and graph the position, velocity, and acceleration of their hand. Then the students setup up another motion sensor facing the first and move their hand between the two sensors. Since students can simultaneously view position, velocity, and acceleration graphs, we are able to discuss the derivative and integral relationships among these.

Following these exercises, one of our students was so enthusiastic about the experience that he wrote a reflective article about it for a university publication, saying, "This [derivative / integral relationships] was a difficult concept for me to understand until I went to my general engineering class one day, where we used position sensors and a laptop to understand the same concept with DataStudio®. The program automatically created graphs of position, velocity, and acceleration in real-time. As we moved our hands closer to and farther from the sensors at different speeds, we could see the impact the speed change made on the graphs of position, velocity, and acceleration. We had worked through similar problems on paper in calculus class, but the relationship between the functions was still vague at best. I understood the concept better after playing with sensors for half an hour in my general engineering lab than I did after hours of solving calculus homework problems."[5]

Conclusions

Results of the educational experiment will be published when analysis is complete. Additional laboratories under development hold great potential for exciting learning—a simulation of the forces and motions involved in bungee jumping, a lab that studies oscillation from a signal generator's current output all the way to a mechanical signal created by a string attached to a speaker cone.

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