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Five-minute Demo: Developing an Intuitive Understanding of Support Reactions Using an Interactive Teaching Activity

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Developing an Intuitive Understanding of Support Reactions Using an Interactive Teaching Activity

Abstract

The ability to quickly and accurately find support reactions for simply supported beams is essential for students moving forward in the fundamental structures courses in civil engineering degree programs. Students who simply try to memorize a procedure lack the insight to assess the validity of their answers and typically struggle on problems with unique loadings. To help statics students develop a more intuitive understanding of how loads distribute in a simply supported beam, an interactive teaching activity was developed that combines physical behaviors with numerical calculations. Students model a simply supported beam using a standard wood ruler, which is supported on each end by small digital scales, and a set of small weights. Using a series of guided activities, students first estimate, then calculate, and finally physically observe the portion of a load carried at each end of the loaded ruler as indicated by the scales. Students progress from single point loads to triangulated distributed loads and prove superposition approaches are valid through the process. This paper provides images of the activity set-up along with the handout students receive to guide them through the lesson.

Introduction

The constructivist learning theory argues that learners create meaning and knowledge based on their experiences and that knowledge cannot be "mapped" onto a learner by a content expert [1]. Linking new knowledge to previous knowledge learned experientially has been shown to create more durable learning [2], [3]. Typical STEM instruction follows a *tell-practice* framework that consists of the instructor sharing key information and the student practicing, which requires students to attempt to link what the instructor is saying to their previous knowledge prior to gaining experiential knowledge. The past experience of students can vary greatly and fundamental instruction that does not address existing misconceptions or current gaps in a student's experiential knowledge can lead to inaccurate interpretations and further reinforce misconceptions making them even more difficult to correct [4]. Carefully crafted activities that guide students through an experiential learning process prior to delivering instruction has been shown to improve student performance and create deeper learning with the ability to transfer the knowledge to new situations [4]. Other research has also shown that new material that is linked to existing knowledge causes less anxiety or fear in learners, leading to improved learning [5], [6].

With this research in mind, a hands-on activity was created that combines physical demonstrations and calculations to experientially introduce students in a statics course to the concepts of distributed loading, resultants of loads, and superposition. The activity was designed to be implemented midway in the statics course, just after students learn to find the support reactions on a simply-supported beam with a single transverse point load and after they have calculated centroids. In the activity, students explore of a variety of loading conditions in an effort to highlight the effect of the loading geometry on support reactions and to experientially demonstrate resultants and superposition. The activity is supported by follow-up instruction, example problems and homework practice problems. A copy of the activity is included in the Appendix.

Hands-on Activity Description

Working in groups of two or three, students receive the activity handout, two small desktop scales, a wooden ruler, a set of small weights, and two pieces of two-inch long half-round, which is a general purpose molding and can be found in eight foot lengths for a few dollars at any home improvement store. The students are instructed to place the scales approximately eight inches apart with one of the half-rounds placed near the center of each scale. The ruler should be carefully set on the half-rounds, and the scales and half-rounds adjusted until the zero and 12 inch marks on the ruler are supported directly over the two half-rounds. Prior to adding any weights to the ruler, the students are required to tare the scales. The general activity setup is shown in Figure 1. Because the standard inexpensive school rulers are in U.S. customary units, the inexpensive weight sets typically come in units of grams, and the scales measure in grams, the activity comes with a disclaimer that is both written and verbally shared reminding students that grams are not a force and mixing units is not considered a best practice.

Groups are required to work through the activity handout independently, with the instructor moving throughout the room to observe, answer questions and generally keep groups on track. The activity progresses students through seven different loading conditions. For each loading condition, students are given a schematic of the beam as shown in Figure 2. For the initial load cases, students are required to calculate the support reactions using statics after first drawing the free body diagram and estimating the reactions. They verify their mathematical results by adding the equivalent load to the ruler and reading the scales. As they progress through the activity, students are required to use results they observed in the previous beams to estimate the next beam's support reactions before measuring the reactions using the ruler, weights and scales. Each load case is followed by a thought question to encourage students to reflect on different behaviors or mathematical patterns.

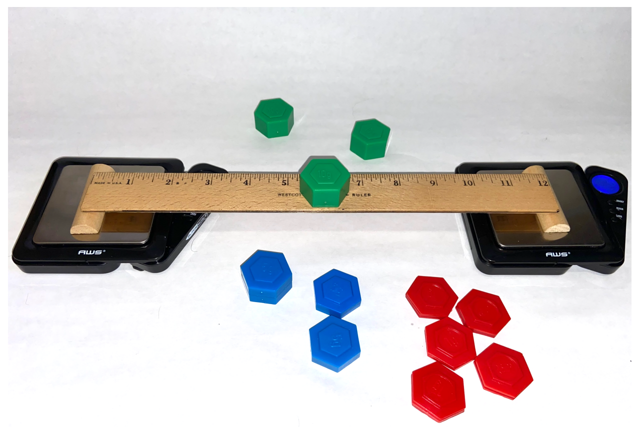

Figure 1: General system setup showing half-rounds supported on the scales and the ruler supported at the zero and 12 inch marks.

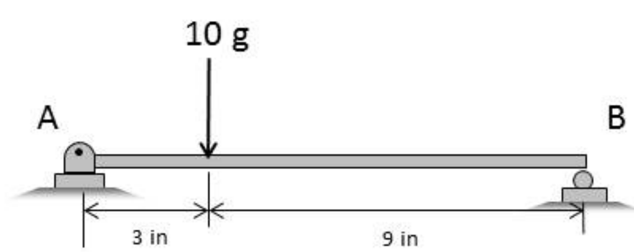

Figure 2: One of seven schematic beam loadings for which students estimate, calculate and finally measure the support reactions.

The first load case is very simple with 10 grams added at the ruler mid span (Figure 1). The students are not asked to solve the statics equations for this loading condition, but are required to verify their estimated support reactions using the ruler and scales. This allows them to identify any errors in their set ups.

Figure 2 is the second loading in the activity. The load is a placed one-quarter of the total length away from support A and using statics the students should determine the vertical reaction at A as three-quarters of the applied 10 grams while B's reaction is one-quarter. Students are asked to identify any geometric patterns they observe and should note the support three quarters of the length from the load only receives one fourth of the load, while the support one fourth of the length from the load carries three quarters of the load.

The loading in Figure 2, is followed by two separate five gram loadings as shown in Figure 3, with the first five gram loading at four inches from support A and the second five gram loading at two inches from A. For each of the five gram loading locations, students are instructed to refer back to the geometric relationship observed for the beam in Figure 2 and estimate the reactions. The accuracy of their estimates is immediately assessed by loading the ruler and reading the scales. They are reminded verbally by the instructor to go back and identify and correct any errors in their estimates.

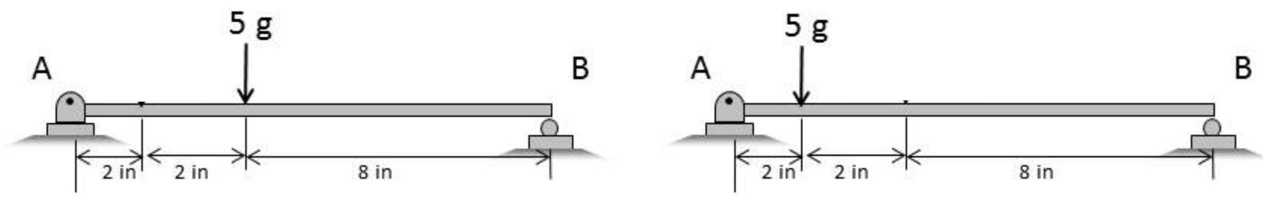

Figure 3: Varying location of the 5-gram load to practice using geometric ratios to find support reactions and set the groundwork for superposition.

The activity continues with students combining the loads from Figure 3, so the beam is carrying a total of 10 grams as shown in Figure 4. For this loading condition, the students immediately load the ruler and record the scale readings. The students are instructed to sum the support reactions at A for the two loading conditions in Figure 3 and compare this to the support reaction found at A for the loading in Figure 4, which should be equal. After also comparing the results for support B, students are asked to write a summary of what they have observed about the behavior of the loading as their first exposure to superposition. Figures 3 and 4 are reintroduced in a later class when superposition is formally introduced.

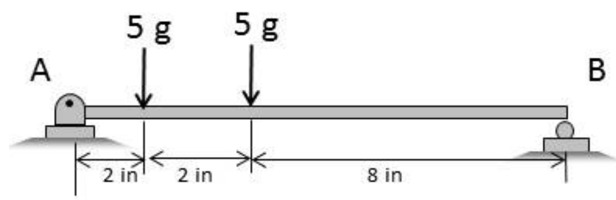

Figure 4: Combined loading used to introduce the concept of superposition with the beams in Figure 3.

The final two loadings demonstrate distributed loads and resultants. Figure 5 represents a five-inch-long, uniformly-distributed load of 2 grams per inch spaced evenly beginning at ½ inch from point A and ending at 5 ½" from point A. Students must reflect on the possible support reactions if they summed the reactions for each individual 2-gram load. They must also indicate what the total load is on the beam (10 grams) and identify where the center of mass occurs for this uniform load (three inches from point A). Finally, students are instructed to refer back to the beam shown in Figure 2 and compare the support reactions and the loading.

Figure 5: Uniformly distributed load that provides equivalent reactions to Figure 2.

To push students in their exploration of distributed loading versus resultant loading, the final triangular loading condition shown in Figure 6 is investigated. This loading has a resultant of 10 grams and students are required to move the load on the ruler until the support reactions match those found for the beams in Figures 2 and 5. Students are required to identify where the center of mass of their triangular load occurs and determine how that compares to the loadings in Figures 2 and 5. Students are asked to reflect on what they can learn from this for finding the reactions for distributed loads.

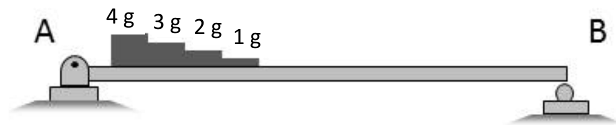

Figure 6: Distributed load students use to find equivalent reactions to Figures 2 and 5.

Student Impact:

This activity was implemented in five sections by two instructors trained in active learning methodologies. Three different pre- and post-assessments were conducted for these classes and 77 students completed all three assessments and gave permission to use their results. One assessment was an end of term survey that asked students how helpful different class activities where to their understanding of the material. This beam activity only scored a 3.23 out of 5 on a Likert scale where 1 was 'Not helpful at all', 3 was 'Somewhat helpful', and 5 was 'Very helpful, it was why I understood the material'. This would indicate that students didn't necessarily see great value in the activity, which is not surprising as there was limited immediate impact for solving statics problems. However, there was a marked increase in the number of students using the geometric relationships to determine the support reactions of single point loads, a method that was highlighted by the activities assigned to the beams in Figures 2 and 3. For the course instructors, the main impact of this activity was observed when load cases from this activity were revisited just before the concepts of superposition or resultant forces were taught and the students were able to describe the observed behaviors. The students' questions and comments indicated they were linking their activity observations to the new topics of superposition and resultant forces.

Conclusion:

This paper presents a hands-on activity designed to develop intuition for students in the basic statics concepts of support reactions, resultants, distributed loads, and superposition. The activity combines calculations with physical measurements and reflective thinking to improve students' ability to estimate reactions and intuit how loads distribute through a simply-supported beam. The activity was crafted to guide students through an experiential learning process prior to delivering instruction on resultant loads or superposition in an effort to support a constructivist learning environment.

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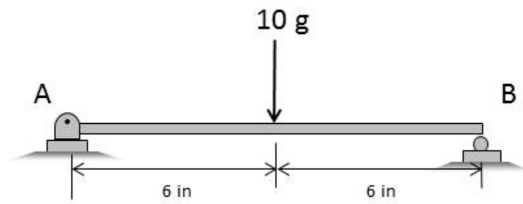
Appendix: Lesson Activity

Lesson 14 Activity 1 – Page 1

Forces have units of lb-force or Newtons (mass * gravity). A mass with units of grams is not a force. However, for simplicity & convenience on this activity we will use grams as a surrogate force.

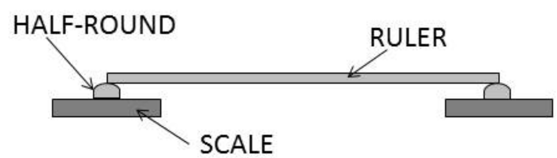
1. a) Draw the free body diagram for the following system.



b) Can you guess the value of A_x (give result in grams)?

c) Can you guess the value of A_y and B_y (give result in grams)?

2. Place 2 half rounds on top of 2 scales. Balance a ruler on the half rounds. Because A_x = 0 for this particular case, we will use roller supports at both A and B. (Figure →)

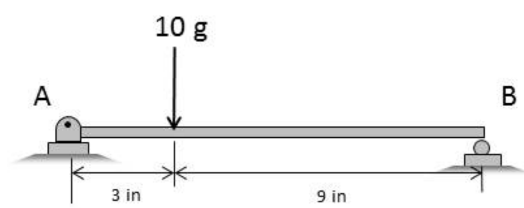


This system is only partially constrained because a force applied in the x direction will cause movement. We will only place vertical forces.

Once the system is set up, press the tare button on each scale. The scales should both read 0.0 g.

3. Recreate the system from (1) by centering a 10 g mass at 6 inches. Do the scale readings match your estimations?

4. a) Draw the free body diagram for the following system.



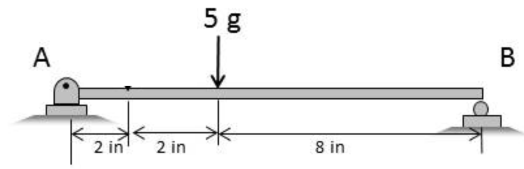
b) Can you guess the value of A_x (give result in grams)?

c) Can you guess the value of A_y and B_y (give result in grams)?

d) Solve for A_x, A_y and B_y using equations of equilibrium. Were your guesses correct? Do you notice any geometric patterns?

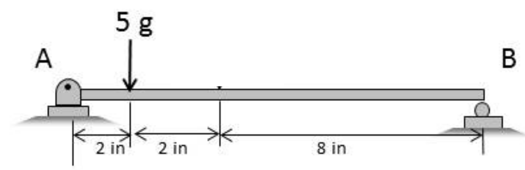
e) Place a 10 g mass at 3 inches on the ruler. Do the scale readings match your calculations?

5. a) If you were to place a 5 g mass centered at the 4 inch mark what do you expect the vertical reactions at A and B to be based on the geometric relationships observed in question #4?



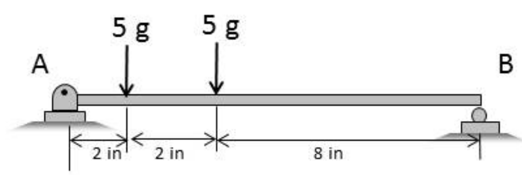
b) Place the mass on the ruler and verify your prediction. What were the scale's results?

c) If you had placed the 5 g mass at 2 inches, as shown, what would you expect the reactions at A and B to be?



d) Place the mass on the ruler and verify your prediction. What were the scale's results?

e) Place a 5 g mass at both locations as shown. Notice the reaction at A should be the sum of the reactions at A from steps (b) and (d) and the reaction at B should be the sum of the B reactions from steps (b) and (d). What does this tell you about the behavior of loads?



6. If you wanted to support the 10 g mass while minimizing the load at support B, where would you place the load? How low can you get the value of the reaction at B, while still supporting the 10 g?

Lesson 14 Activity 1– Page 3

7. a) Place five 2 g masses on the ruler as shown (alternatively – two 1g masses can be stacked for each 2 g mass shown). The masses should be touching each other and span from 0.5 inches to 5.5 inches. The middle mass should be centered at 3 in. According to the scales, what is the support reaction at A and B?

b) Draw a free body diagram for this beam.

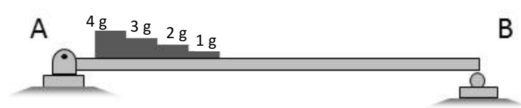
How many forces would you have to include if you summed moments about A? ________

What is the total weight you applied? ____________________________________

Where is the center of mass of the total weight? _____________________

Compare the total weight and center of mass location to the beam in question 4. How do the support reactions compare between beams from #4 and #7? What can you learn from this for finding reactions of a distributed load?

8. a) Can you place the triangular shaped distribution of mass onto your ruler so that the scale at A and B read the same as they do in questions 4 and 7?



b) Where is the center of mass of a triangle? Where is your center of mass and how does it and your total mass compare to questions #4 and #7? What can you learn from this for finding reactions of a distributed load?