

Teachers' Guide:

While we have done our best to guide you through every step of the experiment, we suggest you try to follow the guide by yourself to see which points your students might need clarification on, as well to get a sense of which parts of the experiment are more difficult (we had a hard time keeping a constant stream of pennies for example).

We highly suggest against buying the “fun size” or “bite size” bars. Even though it might be cheaper to do it that way, they tend to have a large cross section relative to their lengths, and so it may take more than 5 dollars in pennies to get one to break.

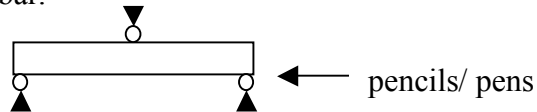
Answers to Questions:

1. Results will vary.
2. Results will vary.
3. Results will vary.
4. Results will vary.
5. Results will vary. However, the strongest bar will usually not require the most amount of pennies to break since strength is determined by thickness, composition, etc.
6. There are a lot of hidden variables – little differences between each experiment. The following is a short list of hidden variables which may affect the number of pennies required to break a bar of chocolate:
 - Even when using mass-produced chocolate, not every chocolate bar is exactly the same.
 - The rate of adding pennies to the cup will be different from experiment to experiment, even if they try their best to be consistent
 - Not every penny weighs the same
 - Groups will add their pennies to the cups from different heights
 - Handling of the chocolate may affect the measured weight under which the fail (scratches, melting etc)
 - The space between tables will not be exactly the same

Different types of chocolate fail at a different weight because their properties are inherently different. White, milk, and dark chocolate will contain different ratios of milk to cocoa ratio. Chocolates with different types of nuts will have different sizes of nuts contained within them. Chocolates can have different sized pores inside them (as result of manufacturing), and different chocolates can have different cross sectional areas.

7. Generally, if the grooves are sharp, chocolates will tend to fail under a lesser weight if the grooves were pointed down (in the direction of the weight). This is because the lower face of the chocolate will be under tension (pulled apart) while the upper face will be under compression (pushed together). Commonly, a crack is more easily formed in the tension side during a 3-point beam test. A notch is a stress concentrator, and thus placing it on the tension side will promote faster failure.

8. Cross sectional area is in direct proportion to the weight required to break the chocolate. A thicker bar of chocolate will require more weight to break because the weight can be dispersed over a larger area. In a thin bar of chocolate of the same type, less weight would be required. You can also prove this mathematically using the formula for stress. If the load was kept constant, but the cross sectional area was made larger, the resulting stress would be lower.
9. There are many, so answers will vary
- rate of pennies
 - instrumental error
 - human error in reading the instruments
 - partial melting of the chocolate
10. For more precise measurements:
- the bar should be loaded with pencils or pens at the outer loading points under the bar.



- climate controlled environment
- a more precise method of adding mass

Typical Values	Milk	Dark	Goodbar	Crunch
length (cm)	13.8	13.7	13	13.8
width (cm)	5.5	5.5	5.4	5.5
thickness (cm)	0.5	0.5	0.7	0.7
Strength (MPa)	0.72	0.81		

Additional Aspects to consider if your lab is equipped with:

If you have a microscope available to you:

- Looking at the surface of the chocolate should reveal imperfections (bumps, pores etc).
- Looking at the fracture surface of the chocolate should reveal that obstacles (rice crispies, peanuts etc) are not all placed in the exact same position.

If you have a mass balance available to you:

- Find the mass of the pennies + cup + string that caused the chocolate to break. This will give a more relevant measure of force required to cause failure than the number of pennies alone.

If you have a stopwatch available to you:

- Measure the rate at which pennies are added to the cup and compare that rate from bar to bar, and from group to group. Rate can be calculated simply as number of pennies funneled divided by the time require to funnel them.

Alternative or Extra experiments if you have leftover time or chocolate:

Try repeating the experiments with a shorter distance between two desks or with shorter pieces of chocolates (you can use the ends of the broken chocolate from the original experiment). Or try replacing the string with a flat shoelace.

Creep:

Creep is time dependent plastic deformation. In most structural materials, it only comes into play at high temperatures, but chocolate, an organic solid, does creep at room temperature. You can easily see creep effects in the chocolate by suspending a set amount of pennies in the cup (less than the amount required to break it in the original experiment) and simply waiting. For example, if a milk chocolate bar is known to break at 100 pennies, try placing 90 pennies in a cup and slowly suspending it in the same fashion as in the original experiment. Measure the amount of time required for the chocolate to break. Do you think you would have to wait longer or shorter if you placed less pennies in the cup? How long do you think is appropriate to wait (if you place 10 pennies in the cup and wait a whole day, do you think the chocolate would break?)

Stiffness:

Stiffness is a measure of how much a material resists changes in shape. In this case, stiffness can easily be observed by the amount of bending that occurs in the chocolate. Because chocolate is relatively stiff, there will not be a lot of bending before it breaks. Try placing a small amount of pennies in the cup and measuring the deflection in the chocolate (the displacement at the center from the unloaded position to the loaded position). Increase the number of pennies by set amount and measure the deflection again. Continue doing this until the chocolate begins to creep or break. Stiffness can be calculated from the formula:

$$\text{Stiffness} = \text{Load} / \text{Displacement.}$$

If measured correctly, your different measures of loads and displacement should still yield a single value for stiffness. Is your measure of stiffness consistent? Why or why not?