Math
"Don't Crack Humpty" is a nice example of a rich project that should start with an engineering experience (preferably iterated to give practice with engineering problem solving and to enhance the odds that physics and math insights will arise) and then move into more of a focus on a content area that you need to make a "hook" into.

If all designs and their cost-benefit ratios are put up in a table, groups may note that different solutions have the same ratio or may feel the ratio is not fairly evaluating more costly designs. Ask: come up with theoretical costs and levels survived (they don't need to actually produce any design) that have a ratio of 6. Have them plot all ordered pairs on a graph on the board in one color. Repeat with a new ratio and color

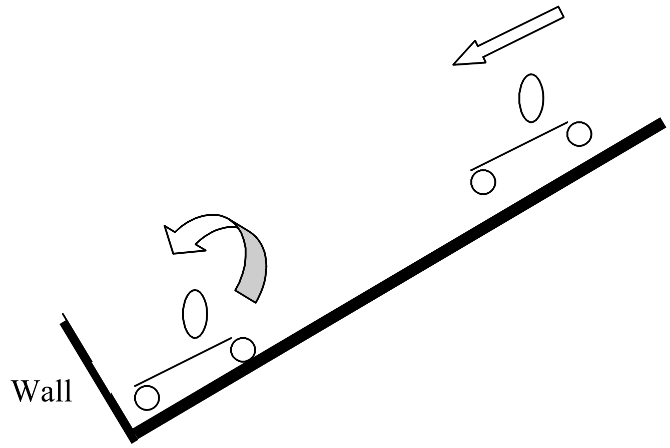
Students will see that these are linear relationships. Does the point (0,0) belong on each graph? Can it be a part of all of them? Well, a 0 cost car can certainly survive a 0 level fall but 0/0 is not a real number! Typically teachers in High school or middle school say it is "undefined" but as a limit we say it is indeterminate, meaning we can't tell what value 0/0 is. Our graph of intersecting lines suggests this interpretation. Level curves for c/l=4 or 6 or 1.5 etc all point to (0,0) and it can't be all of them.

Level curves are a 2-D way to picture 3-D graphs like topographic maps. To better understand these cost-benefit level curves, students can also do a 3-D graph. Call one corner of the room (0,0,0) x=c, y=l, z=c/l. Explain the height of the room as the z-axis and each point in the x-y plane (floor) is a particular design with its cost & success level.

Each student should make the tip of a pointer finder a point and they should graph one data point (hold their finger above the correct spot on the floor at the right height). Ex: A car costing $12 surviving level 3 is plotted 12' along one wall, out 3 and then up 4'.
If everyone graphs designs with the same ratio, they will see their fingers are at the same height. If 20 students plot different designs they will start to see the shape of the curve (points going up as they near the "c" axis and down as they near the "l" axis.

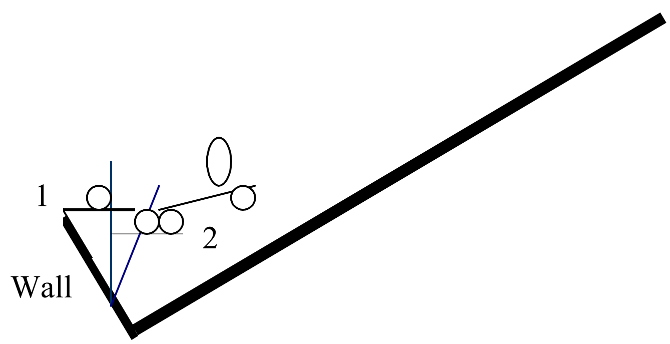
Physics

While testing this activity all groups grappled with the fact that the cars would fly up on contact and bring the egg to the wall.



The center of gravity of the car was above the plane of the chassis. So why doesn't the car flip forward at low speeds? As the car rotates, the center of gravity has to rise up, thus requiring potential energy. Therefore, the terminal velocity and its associated kinetic energy need to be sufficient to rotate the center of gravity up and over.

Students can determine the location of the center of gravity using the standard lab (hanging it from more than one point & finding the intersection of the plumb lines from those points) They can then measure the change in height of the center of gravity from its location at impact to its greatest height as the car rotates around that impact point.



Calculate difference in height between center of gravity in 1 & 2 = Δh of cg.

Investigative Questions:

1. What happens to the speed of the car as the angle of the ramp increases? (It speeds up.)

2. What happens to how far the center of gravity has to rise in order to “flip” the car forward as the angle of the ramp increases? (It decreases. The steeper it is the higher the cg is to begin with and the less it has to go up as the car rotates. Extreme example – if you stand your car on end it probably falls over the egg)

   How do these 2 conclusions affect the likelihood of a flip-over as the ramp angle increases? (Both increase the likelihood so the difficulty of avoiding a flip-over grows considerably as the ramp gets steeper.) Students can do some estimates of speed once they see the height (or angle) at which the car tips up and over. The potential energy is mgh <– starting height – ending height of center of gravity (or any point).

   Solve using KE=1/2mv^2
   So its speed is v = (2*g*h)^1/2

   Hence, this energy should be able to lift the car up and over a far smaller height but much of the KE is lost in the collision.

3. Once they see the crucial ramp angle and associated rise in the center of gravity, they can calculate what portion of the KE is going into that rotational motion.

= (m*g*Δh of cg) / (m*g*car ht change)

4. Can this influence design? If we can add a bumper/crumple zone then more KE is lost and less will go into lifting the car. If we raise the point of contact (pivot point) the center of gravity will have to flip up higher and we can limit flip over (more energy needed).

Cost benefit:

1. Students could research different cars and compare each car’s cost with its score on the 5 star crash rating (federal ranking available online).
2. Do more expensive cars have a better rating?
3. Is their cost/benefit score better?
4. What considerations would they have in evaluating a car’s safety?
5. Why don’t we build super sturdy vehicles (tanks)? The trade-offs that engineers face force compromises - optimal solutions are balancing acts between competing variables (cost, fuel efficiency, safety in a crash). Crash avoidance (which is better than crash survival) requires more maneuverable cars.