Stunt Barbie – A Laboratory Practicum Combining Constant Velocity and Constant Acceleration

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In preparing to teach the advanced physics course at my high school, I found it useful to work through the end-of-chapter problems in the book[1] used by the advanced class. A problem on motion in one dimension involved a stunt woman in free fall from a tree limb onto a horse running beneath her.[2] The problem presents a connected learning opportunity for students because it requires the use of the constant velocity model

$$x_f = v^*t + x_i \qquad (1)$$

and the constant acceleration model

$$y_f = ½ *g^* t^2 + v_{yi}{}^*t + y_i \qquad \text{(where } g = 9.8 \text{ m/s/s)} \qquad (2)$$

to solve it. I named the stunt woman Barbie and created an activity titled "Stunt Barbie."

Although Barbie is in the title, a steel marble with some VELCRO® brand hook-and-loop fastener on it (Fig. 2) represents the stunt woman in free fall. Likewise, a constant velocity dune buggy[3] represents the running horse. An electromagnet[4] drops the marble. When the dune buggy reaches the position they have calculated, the students turn off the electromagnet. The position represents how far the dune buggy will travel as the marble ball falls.

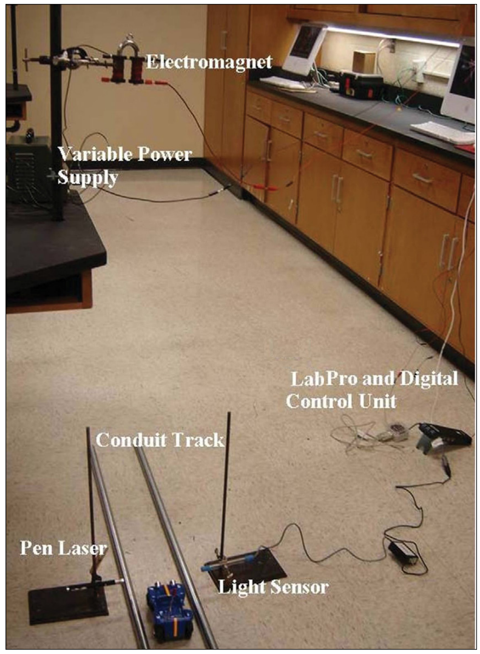

Fig. 1. Physical setup for the activity.

Fig. 2. Modified dune buggy, marble, and electromagnet.

The setup

Figure 1 shows the overall setup for the activity. Figure 2 shows the electromagnet mounted on a pole/stand so it can be adjusted to various heights. The setup uses heights between 1.25 m and 2.75 m. Although I have a "pole" at the end of each lab bench in my classroom, a significantly greater height is preferable. The conduit serves as a "track" to keep the dune buggy moving in a straight line.

The activity allows each group of students to work with a different set of variables. I assign each group a different height from which to let the marble fall and a different dune buggy to use. Each dune buggy has been slightly modified by removing the seat and adding some VELCRO® brand hook-and-loop fastener to minimize the marble bouncing (Fig. 2). To produce different velocities in the dune buggies, I placed two batteries in some and one battery and an aluminum slug in others.

Introducing the activity

When introducing the activity to my students, I mention that we've all seen movies[5] and television shows that show a person falling from a height into a moving vehicle. I show them a television commercial[6] with the same stunt. I explain that this activity will provide a chance for them to physically recreate the stunt and have Barbie (or something resembling Barbie) fall into a moving vehicle! Not only do these two examples present the challenge, they also motivate and excite the students.

Completing the stunt

In order to successfully complete the "stunt," the students need two pieces of information: the velocity of the dune buggy and the assigned height from which the marble will be dropped. The groups must experimentally determine the velocity of the dune buggy. Most groups simply recall and repeat a previous experiment. Using the constant accelera-

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tion model for free fall, the students calculate the time it will take the marble to fall from the assigned height to the (seat) height of the dune buggy. Combining the constant velocity of the dune buggy and the time the marble is falling allows them to determine how far the car will travel while the marble is falling. Most groups decide it is easier to place a piece of tape on the floor marking the location of the dune buggy when the electromagnet should be turned off. The groups take approximately 20 minutes to gather data and make the necessary calculations.

Assessment

The main goal of the activity is for the students to make a prediction based on the data they gathered. The assessment has two distinct parts: 1) the calculations and 2) the results of the "stunt." The activity is assigned a value of 10 points, as described below:

- ➢ Up to eight points for the work completed in making the calculation(s). These calculations include the determination of the velocity of the dune buggy, the calculation of the time the marble is falling, and the calculation of the resulting displacement of the dune buggy.
- ➢ **Stunt Points:**
  - Two points for the marble landing and staying in the seat area of the dune buggy on first try. (NOTE: Two points will also be awarded if the marble lands in the seat area but bounces out.)
  - One point for the marble landing in and staying in the seat area on the second try. (NOTE: One point will also be awarded if the marble lands in the seat area but bounces out.)

Sample calculations

Data:

Assigned "Barbie drop height"	2.00 m (This represents the initial height of the marble.)
Height of dune buggy	0.05 m (This represents the final height of the marble.)
Dune buggy velocity	0.500 m/s (a given value or determined experimentally by the students).

Determining the time (t) the marble is in the air:

Using Eq. (2): $y_f = ½ *g*t^2 + v_{yi}*t + y_i$,

where $g = 9.8$ m/s/s

$y_f = 0.05$ m

$y_i = 2.00$ m

$v_{yi} = 0.0$ m/s (initial velocity of the marble).

Rearranging and solving Eq. (2) for time t:

$$t = \sqrt{\frac{2(y_f - y_i)}{g}} = \sqrt{\frac{2(0.05\,\mathrm{m} - 2.00\,\mathrm{m})}{-\,\frac{9.8\,\mathrm{m}}{\frac{\mathrm{s}}{\mathrm{s}}}}} = \sqrt{\frac{2(-1.95\,\mathrm{m})}{-\,\frac{9.8\,\mathrm{m}}{\frac{\mathrm{s}}{\mathrm{s}}}}}$$

$$= \sqrt{\frac{-3.90\,\mathrm{m}}{-\frac{9.8\,\mathrm{m}}{\frac{\mathrm{s}}{\mathrm{s}}}}} = \sqrt{0.398\,\mathrm{s}^2} = 0.631\,\mathrm{s}.$$

Determining when to turn the electromagnet off:

As described above, the students need to know the position the dune buggy has to be at when they turn the electromagnet off. Essentially, they must determine how far ($x_f - x_i$, or just simply Δx) the dune buggy travels while the marble is in the air.

Using Eq. (1): $x_f = v*t + x_i$,

where $x_i = 0.00$ m (the position directly below the marble)

$v = 0.500$ m/s

$t = 0.631$ s

$x_f = (0.500 \text{ m/s} * 0.631 \text{ s}) + 0.00$ m

$x_f = 0.316$ m.

This means the students should turn the electromagnet off when the dune buggy is 0.361 m away from the position directly below the hanging marble.

An optional enhancement: Automating the release

Having the students manually turn off the electromagnet does introduce some room for error. After showing this activity at a local physics share meeting, a colleague suggested improving it by developing a method to have the marble drop automatically. In order to accomplish this automation, I used a Vernier Digital Control Unit, a Vernier Light Sensor[7] (both

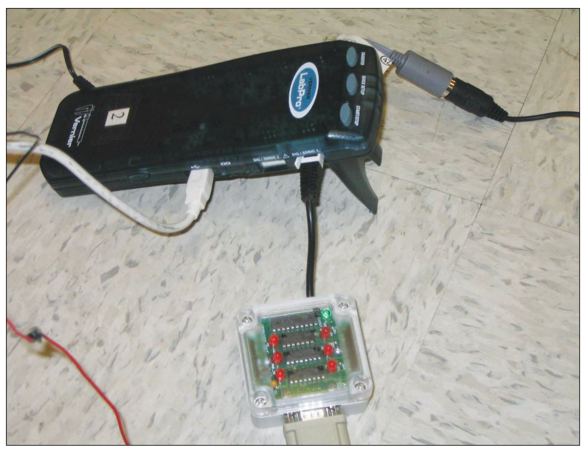
Fig. 3. The Vernier Digital Control Unit.


Fig. 4. The Vernier Light Sensor and pen laser that serve as a switch.

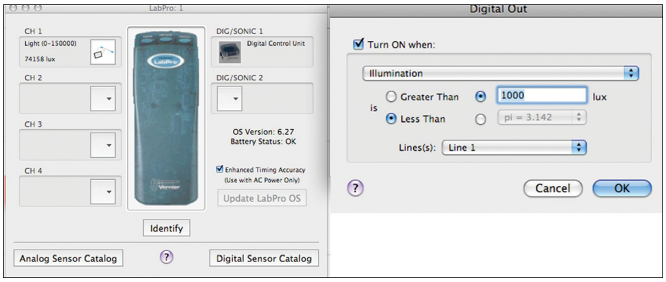

Fig. 5. LabPro and DCU settings.

connected to the LabPro as shown in Fig. 3), and a pen laser to act as a switch to turn the electromagnet off (Fig. 4). Using the Logger Pro software,[8] the DCU can be programmed to open a switch, i.e., turn off the electromagnet when the light intensity drops below a specified value. This switch is set up as follows:

1. Connect the DCU to DIG/SONIC 1 on the LabPro, and the light sensor to Channel 1.
2. Open Logger Pro and select "Set-Up Sensor" under the Experiment menu.
3. Click on CH1 and select a light sensor.
4. Click on DIG/SONIC 1 and select the DCU.
5. Click on DIG/SONIC 1 again and choose "Digital Out."
6. Select the "Turn ON when:" and also the "Less Than" buttons. Set the Illumination value to a value significantly lower than the value displayed (see Fig. 5). Click OK.

The students then place the "switch" (laser and light sensor) at the position they have determined for their dune buggy and drop height. Simply hit the "Collect" button and have the students release the dune buggy.

Some helpful hints

Having done this activity for several years, I have learned a few things that serve to improve the experience. First, it is useful to have a "plumb line" (a string with a 20-g mass attached) available that the students can hang under the marble so they know the exact position on the floor directly beneath the marble. Second, it is also helpful to use a digital video camera to record each attempt. Replaying the attempt allows everyone to see exactly where the marble hits if it does not stay in the dune buggy.

Conclusion

A number of different reasons support the success of this activity. From the instructor's point of view, the results are excellent and very reproducible. It also provides a solid connection and application of the constant velocity and constant acceleration models. In addition, the activity also may easily be modified to fit different abilities of the students or the time available to complete it. For example, the instructor may choose to provide the velocity of one dune buggy to be used by all the groups.

Finally, once projectile motion has been studied, this activity can be revisited to reinforce the independent nature of the horizontal and vertical aspects of projectile motion. The (horizontal) motion of the dune buggy did not affect the (vertical) motion of the falling marble. A culminating discussion or demonstration would be to relate this activity to the famous "Monkey and Hunter" problem. The dune buggy serves as the projectile and the marble serves as the monkey.

Generally, students find the activity to be fun, interesting, and relatively easy to obtain success. Many students list "Stunt Barbie" as one of their favorite activities on course evaluations.

Acknowledgments

I would like to thank David Vernier[9] for his help with configuring the Digital Control Unit so the marble would drop automatically. Appreciation is also given to the many reviewers who made insightful suggestions to enhance the activity.

References

1. R. A. Serway and J. Faughn, *College Physics*, 5th ed. (Saunders, New York, 1999).
2. Ref. 1, Chap. 2, Problem 60, p. 50
3. Electromagnet, Order Code #A31132-00, price $12.95. Edmund Scientific, 60 Pearce Ave., Tonawanda, NY 14150-9711; www.scientificsonline.com.
4. The Constant Speed Buggy, Order Code SKU M-09-F, price $6. The Physics Toolbox, 148 Bromley Dr., Wilmington, DE 19808; www.physicstoolboxinc.com.
5. "Hidalgo," film directed by Joe Johnston (distributed by Touchstone Pictures, released 2004) 136 min, clip of interest at 1:19.30 to 1:19.50 (Chapter 11).
6. Farmers HelpPoint Commercial, "Trouble Getting to Work" YouTube; www.youtube.com/watch?v=XYDEJHVv71s.
7. The Vernier Digital Control Unit, Order Code DCU-BTD, price $61. The Vernier Light Sensor, Order Code LS-BTA, price $55. Vernier Software & Technology, 13979 S.W. Millikan Way, Beaverton, OR 97005-2886; www.vernier.com.
8. Vernier Logger Pro 3.6.1 Software, Order Code LP, price $189. Vernier Software & Technology, 13979 S.W. Millikan Way, Beaverton, OR 97005-2886; www.vernier.com.
9. David Vernier at Vernier Software and Technology, Beaverton, OR (www.vernier.com).

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