An Intensive Energy Conservation Experiment
Comparing the PocketLab Teacher Geek® Cart
with a ZéCar Flywheel Powered Car

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Introduction

In addition to being a fascinating toy, the ZéCar flywheel powered car (see Figure 1) can be utilized in physics curricula to study conservation of energy. It is available from a variety of sources, including teachersource.com for under $14. In this lesson students study energy conservation, including gravitational potential energy, translational kinetic energy, rotational kinetic energy, and work done against non-conservative frictional forces, with emphasis on comparing ZéCar with the PocketLab Teacher Geek® cart. Data from PocketLab Voyager's range finder can used to determine translational velocity (see Figure 2) for ZéCar.

Figure 1

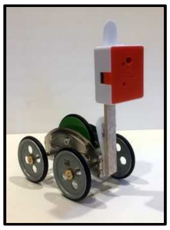

Figure 2

The Experiment

Figure 3 shows the experimental setup. Two boards about 1 meter each in length are propped up at equal heights with some books. (The author optionally used a pair of table leafs instead of boards.) ZéCar is released from rest at the top of the left board with Voyager's IR range finder facing to the right. You will need to adjust the height of the inclines so that when Voyager is released, it will begin to roll down without sliding. A meter stick is placed on the rightmost board for the purpose of measuring the distance that ZéCar travels up that board before coming to a stop. A piece of white foam board, not shown in Figure 1, is held in place where the two boards meet in order to collect range finder data when ZéCar is released and begins rolling down the leftmost board. This foam board is quickly removed just before ZéCar reaches the bottom of the leftmost board. ZéCar can then travel up the rightmost board unimpaired under the power of the flywheel. See the accompanying video.

Figure 3

Student Tasks

1. Determine the initial gravitational potential energy PE_g of ZéCar.
2. Using Voyager's rangefinder, determine the velocity v and translational kinetic energy KE_t of ZéCar after rolling from the start position down to where the two boards meet.
3. By applying conservation of energy to the first part of the trip down the leftmost ramp, and then applying conservation of energy once again to the second part of the trip during which ZéCar moves up the right most ramp until coming to a stop, come up with a pair of simultaneous equations in two unknowns:
    a. The rotational kinetic energy KE_r of the fly wheel car the instant that it reaches the bottom of the leftmost ramp.
    b. The work **per meter** (W_f) of motion along the ramps required to overcome any nonconservative frictional forces (friction of wheels on ramp, friction in gears, air resistance, *etc*.).
4. Solve this pair of equations for both KE_r and W_f and determine the value for each.
5. What do you notice about the values of KE_t and KE_r, when comparing them?
6. Have your students ever wondered about the kinetic energy of rotation of the wheels versus the kinetic energy of translation of a typical cart used in physics experiments? Is the kinetic energy of rotation negligible or not? Have the students repeat this experiment using the ***Teacher Geek®*** cart that comes with several of the ***PocketLab Science Kits*** to find out.

The diagram of Figure 4 can be helpful for students in their conservation of energy analysis of step 3 above. The two conservation of energy equations should involve g, m, h_1, h_2, L_1, and L_2 as well as the unknowns KE_r and W_f.

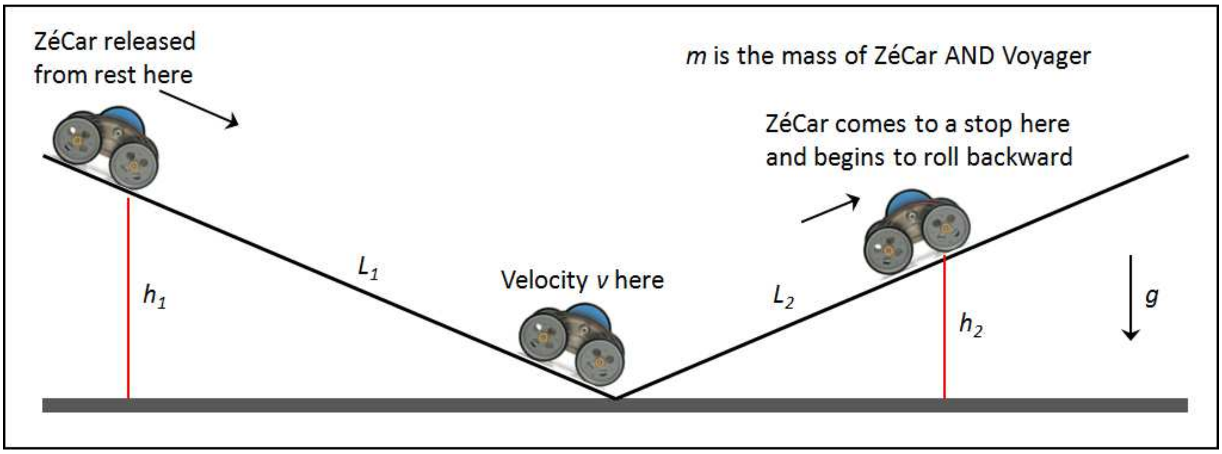

Figure 4

Conservation of Energy Analysis

This discussion is done with reference to Figure 4. The gravitational potential energy mgh_1 is converted into three components after ZéCar rolls down the left ramp: rotational kinetic energy of the flywheel (as well as ZéCar's wheels), translational kinetic energy of the car, and work required to overcome various non-conservative frictional forces. This is expressed in the following equation:

$$mgh_1 = KE_r + \frac{1}{2}mv^2 + L_1W_f, \quad \text{(Equation 1)}$$

where we make the simplifying assumption that W_f is independent of time.

The rotational kinetic energy and translational kinetic energy of the car at the intersection of the ramps are then converted to gravitational potential energy when the car stops on the rightmost ramp as well as into work to overcome nonconservative frictional forces while traveling up that ramp. This is expressed by the following equation:

$$KE_r + \frac{1}{2}mv^2 = mgh_2 + L_2W_f \quad \text{(Equation 2).}$$

Solving equation 2 for KE_r and plugging that into equation 1 reveals that:

$$W_f = mg\left(\frac{h_1 - h_2}{L_1 + L_2}\right) \quad \text{(Equation 3).}$$

Solving equation 1 for KE_r, we obtain:

$$KE_r = mgh_1 - \frac{1}{2}mv^2 - L_1W_f \quad \text{(Equation 4).}$$

Equation 3 allows us to calculate W_f in J/m. This value can then be used in equation 4 to determine the value of KE_r.

Determining the Velocity at the Bottom of the Ramp

One could determine the velocity *at the bottom* of the ramp as follows:

- Use a stopwatch to measure the time to reach the bottom of the ramp.
- Measure the distance traveled with a meter stick.
- Divide the distance traveled by the time to get the ***average*** *velocity*.
- Multiply the average velocity by 2 to get the final velocity at the bottom of the ramp.

There is, however, the disadvantage of reaction time affecting the result when using a stop watch. This is especially of concern with the PocketLab Teacher Geek® cart, as it travels much faster down the ramp than ZéCar. Data from Voyager's range finder in conjunction with the PocketLab app is much more accurate. As an alternative to determining velocity when collecting data for the Teacher Geek® cart, you could use PocketLab 1 or Voyager in conjunction with the VelocityLab app. This technique is nice as VelocityLab will provide a velocity graph for you, but will not work with ZéCar as its wheels are too small to mount on either PocketLab 1 or Voyager.

Using Voyager's range finder will provide position versus time data, as shown in the Excel graph of Figure 5. This graph was constructed from the *csv* file produced by the PocketLab app. Since the car accelerates down the ramp, the position versus time graph is a parabola. Applying the parabolic curve

$y = Ax^2 + Bx + C$ to the data, and using the fact that the derivative $y' = 2Ax + B$ of the position graph gives velocity, one can easily determine the velocity at the bottom of the ramp.

The graph shows that ZéCar is released from rest at 15 seconds and reaches the bottom of the ramp at 23 seconds. From the graph, the parameter A = -0.0137 and B = 0.4073. Therefore, the value of the velocity at 23 seconds is v = 2(-0.0137)(23) + 0.4073 = -0.22 m/s.

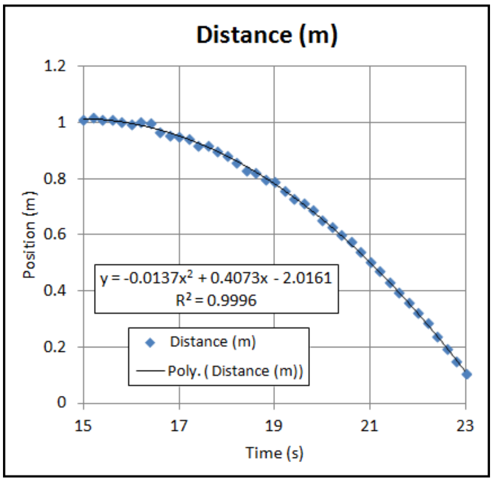

Figure 5

Sample Results

Figure 6 summarizes the experimental results by comparing ZéCar with the PocketLab (PL) Teacher Geek® cart. Several observations are as follows:

1. Although the masses are comparable, the translational velocity of the PL cart is more than 7 times greater than that of ZéCar.
2. With kinetic energy being proportional to the *square* of the velocity, the kinetic energy of translation of the PL cart is more than 49 times greater than that of ZéCar.
3. The PL cart travels twice as far as ZéCar up the rightmost ramp, suggesting that the non-conservative frictional forces are less for ZéCar. This is consistent with the values obtained for W_f, with the W_f value for ZéCar being more than 7 times greater than that for the PL cart.
4. The translational kinetic energy (0.0037 J) of ZéCar is almost negligible compared to its rotational kinetic energy (0.195). In contrast, the *rotational* kinetic energy of the PL cart, though smaller than its translational kinetic energy, is about 23% of the translational kinetic energy.
5. In a manner of speaking, one could say that the roles of translational and rotational kinetic energies are reversed for ZéCar and the PL cart, *i.e.*, for ZéCar, translational kinetic energy is "small", while for the PL cart, rotational kinetic energy is "small".

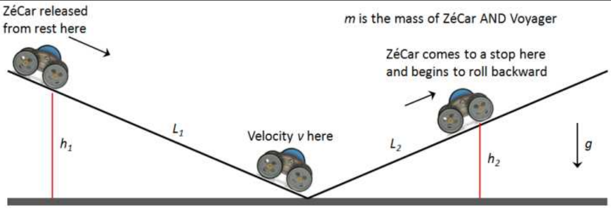	ZéCar 	PocketLab *Teacher Geek*® Cart 
m, (kg)	0.154	0.121
v, (m/s)	0.22	1.85
L_1, (m)	1.075	1.00
L_2, (m)	0.46	0.92
h_1, (m)	0.23	0.23
h_2, (m)	0.09	0.20
W_f, (J/m)	0.138	0.0185
KE_r, (J)	0.195	0.0475
$\frac{1}{2}mv^2$, (J)	0.0037	0.207

Figure 6