# Penguins and Dolphins on a Roller Coaster: Electromechanical Efficiency of a Toy

*Electrical input is compared to mechanical output to determine the percent efficiency for a battery-powered toy in which small plastic figures (penguins, dolphins, dogs, pirates, etc.) are lifted to the top of a roller-coaster-like track, roll down the track and then repeat the journey.*

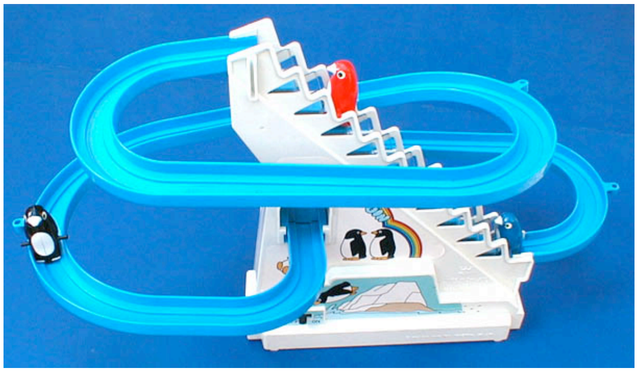

**Figure 1**

**Figure 2**

**Recommended Grade Level**: 8th to 12th (see **More** section at end of write-up for comments)

**NGSS Science & Engineering Practices:**
- Effectiveness and Efficiency
- Analyzing and Interpreting Data
- Using Mathematics and Computation

**Preparation**: involves the following:
- obtaining the devices, likely by ordering online if not otherwise available
- assembling devices (1 hour or less)
- assembling accompanying materials noted below (1 hour or less if readily available)

**Materials Needed**: (**for each group of students**] (see **More** section at end of write-up for sources)
- Device -- penguins, dolphins, dogs, pirates, etc. -- see Figures 1 & 2
- Battery holder -- see Figure 3 for one example, or can use commercial version or devise your own
- Battery, D cell
- 3 alligator clip leads -- see Figure 8 for placement
- Ruler
- Multimeter with connecting probes -- see Figure 4
- Paper clip (bare metal -- jumbo or standard) or brass fastener
- Calculator
- Stopwatch -- or can use any watch or clock that allows timing to seconds
- Balance -- digital balances are very convenient, and inexpensive versions are available

**Figure 3**

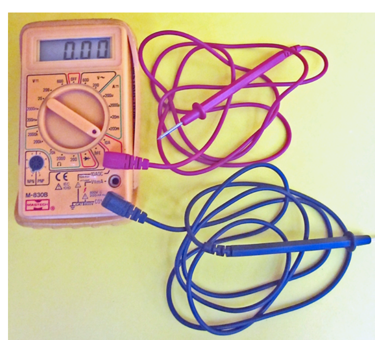

**Figure 4**


Don Rathjen....Exploratorium Teacher Institute....Pier 15, San Francisco, CA 94111.....drathjen@exploratorium.edu

**Background Information**

The toys used in this activity all involve a battery-powered mechanism of some sort which lifts an object from its starting position to an elevated position at the top of a track.

The energy put into the machine to operate the mechanism that lifts the object is provided by the battery, and is called the **input** work.

The lifting of the object from the bottom to the top of the track is what the machine was designed to do -- it is the **output** of the machine. Since this increase in height gives the object greater gravitational potential energy, work must be done in the process., and the work done is therefore called the **output work.**

The comparison of output work to input work is called the efficiency. If there was no friction present, and the design of the mechanism did not waste any of the energy in unnecessary motion, etc., then the output work would be equal to the input work and the machine would be 100% efficient. But no real machine can completely eliminate friction, and so no real machine is 100% efficient. Another way of saying this is that for all real machines, the output work is always less than the input work.

In this activity, you will acquire data which will allow you to calculate the input and output work and compare them to determine the percent efficiency. Since in this activity the input is electrical and the output is mechanical, we can call this the **electromechanical** efficiency.

Electrical Input: $W_{in} = V \times I \times t$

- $W_{in}$ = work input (joules)
- V = voltage (volts) -- volts can be expressed as joules per coulomb (coulomb is a unit of electric charge)
- I = current (amperes, Ior amps) -- amperes can be expressed as coulombs per second
- t = time (seconds)
- in terms of these units , V x I x t can be expressed as $\frac{\text{joules}}{\cancel{\text{coul}}} \times \frac{\cancel{\text{coul}}}{\cancel{\text{sec}}} \times \cancel{\text{sec}}$
- note that coul and sec cancel, leaving only joules, which is the unit of the input Work, $W_{in}$

Mechanical Output: $W_{out} = F \times d = m \times g \times h$

- F = force = the weight of the object being lifted
  - F = ma (Newton's 2nd Law)
  - In the case of a freely falling object
    - F is the force of gravity, which we call weight
    - m is he mass of the object
    - a is the gravitational acceleration, which we call "g" (9.8 or 10 m/s/s),
    - so the **weight of an object is equal to m x g**
- d = distance = the **height** the object is lifted, which we will call **h** -- see Figures 5 &6
- F x d = m x g x h = change in gravitational potential energy
  - note that units of m x g x h are kg x $m/s^2$ x m = $kgm^2/s^2$; these are the fundamental units of a joule, which is the unit of the output work, $W_{out}$


**Figure 5**


**Figure 6**


Don Rathjen....Exploratorium Teacher Institute....Pier 15, San Francisco, CA 94111…..drathjen@exploratorium.edu

**What To Do**
(Note: The procedure items below refer to dolphins, but also apply to any of the devices (penguins, dogs, pirates, etc.).

1. See Figure 7. In the empty battery compartment, insert a paper clip (either jumbo or standard) or a brass fastener under the contact strip for the positive end of the D-cell battery (the positive end is the end with the "knob" on it -- the negative end is flat). This will allow you to easily attach an alligator clip lead. The negative contact is usually a spring or a bent strip that is easier to attach an alligator clip lead to.

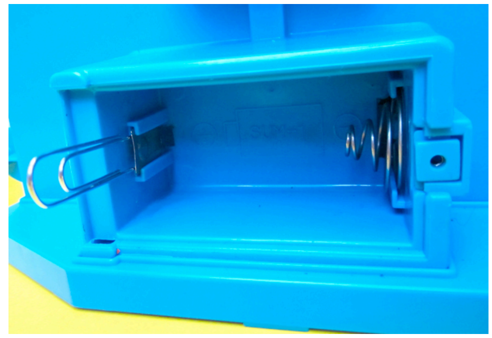

**Figure 7**

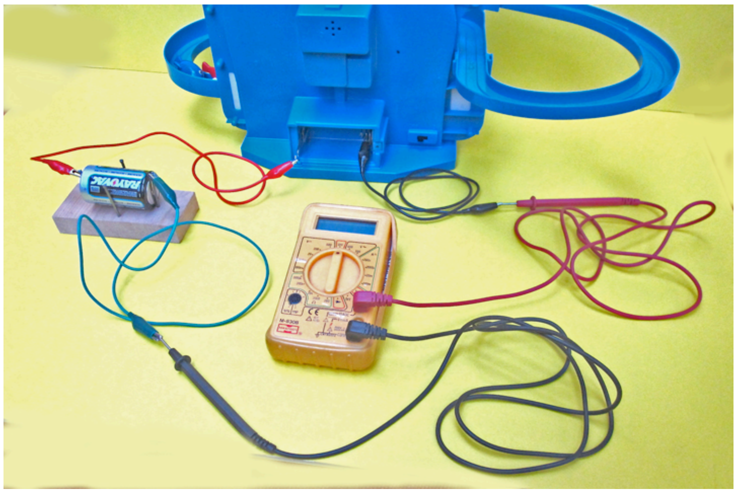

**Figure 8**

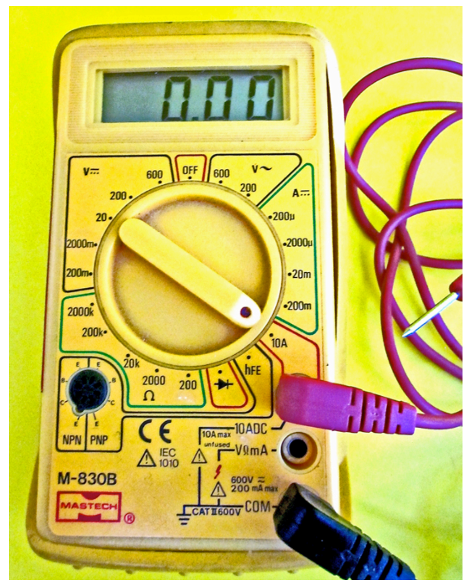


**Figure 9**

2. Hook up the device, the battery and the multimeter in the simple series circuit circuit shown in Figure 8. Be sure the positive end of the battery is connected to the positive terminal in the device's battery compartment. The multimeter should be set to the 10A range, and the probes plugged into the appropriate terminals -- see Figure 9.. When correctly set up, the device should run properly when the device's on-off switch is turned on.

3. Determine the electrical work input to lift a single dolphin. Assume V = 1.5 volts, or use a second multimeter to measure the V across the battery. Measure V in volts, I in amps and t in seconds. Answer will be in joules.

$$W_{in} = V \times I \times t =$$

4. Determine the mechanical work output when a single dolphin is lifted. Express m in kilograms, g in meters/seconds$^2$ and h in meters. Answer will be in joules.

$$W_{out} = m \times g \times h =$$

5. Determine the % Efficiency for the machine lifting a single dolphin. Answer will be dimensionless, since units of both work items are joules, and cancel.

$$\% \text{ Efficiency} = \frac{W_{out}}{W_{in}} \times 100 =$$


Don Rathjen....Exploratorium Teacher Institute....Pier 15, San Francisco, CA 94111…..drathjen@exploratorium.edu

**What's Going On?**
Compare class results for the various machines. Would you describe the efficiencies of the machines in general as low, medium or high?
Energy use is a critical issue in today's world. Engineering design which maximizes efficiency and thereby reduces energy demand is a significant contributor to the effort to create a sustainable environment and economy.

**Going Further**
• Will changing the mass of the object being lifted change the efficiency? As the mass of the object increases, does the electrical input increase as well?
• If you lift two or more objects simultaneously, one right after the other, how will this affect the efficiency?
• Can you think of design changes which might increase the efficiency of the device?
• Figures 10 and 11 show the internal mechanism of a penguin device. This particular device was easily taken apart just by removing a few small screws, although on occasion a device may be glued together, and non-destructive disassembly will be either difficult or impossible. If you have a device which can be feasibly taken apart, try exposing the mechanism, putting a battery in place and turning the device on, and watching the mechanism at work.

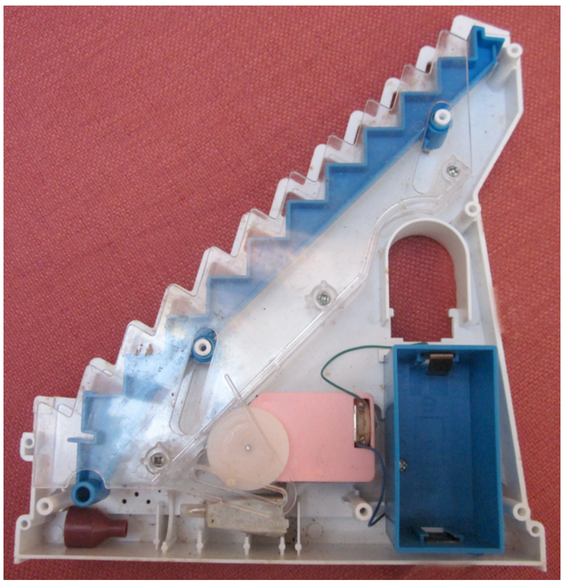

**Figure 10**

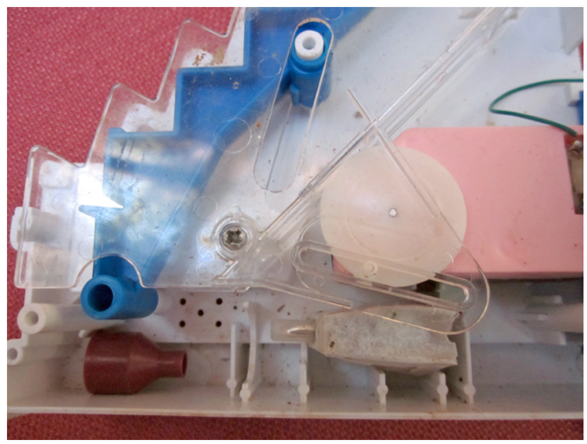

**Figure 11**

**Recommended Web Sites**
• www.exo.net/~donr/activities/Penguins_and_Other_Toys.pdf
• Look up Energy Conversion Efficiency on Wikipedia and note the table giving efficiencies of a range of items, from refrigerators to incandescent lights to solar cells to LED's to mention just a few.

**More**
Grade Level: This activity uses mathematics and units which may not be appropriate for all students in the grade range noted. But energy is a critical theme in science and engineering, and the toys themselves are compelling hooks for kids. The toys provide a great vehicle for illustrating work, kinetic energy, potential energy, energy conversion, power, etc., and they can even be adapted to qualitative use. See the first website above for some additional ideas for use of these and other similar toys.

Sources:
• The penguin toy was available online at Amazon at this writing -- approximately $9.00. You can also try e-bay, toy stores, thrift shops, garage sales, flea markets, or appeals to students.
• Inexpensive multimeters and electronic balances can be found at Harbor Freight.


Don Rathjen....Exploratorium Teacher Institute....Pier 15, San Francisco, CA 94111…..drathjen@exploratorium.edu