Bouncing ball video analysis: Day 1 of the Kangaroo Locomotion Case Study
(Teacher notes in blue, with sample student predictions and brief discussion of correct answers to analysis questions.)

Names:

Introduction

Mechanical energy describes the ability of an object to do work. From a bowling ball knocking down pins, to a frog catching a fly with its tongue, mechanical energy underlies the movement we see all around us in everyday life. Although energy cannot be created or destroyed, it can change forms in two ways: (1) Energy transformation takes place when energy within a system changes from one form to another. For example, a frog's tongue acts like a loaded spring, rapidly converting elastic potential energy to kinetic energy when the tongue shoots out to catch its dinner. (2) Energy transfer takes place when energy is exchanged from one system to another. For example, when a bowling ball collides with the pins, it transfers some of its kinetic energy to them, setting them in motion.

In today's video analysis lab, we'll observe, track and describe the motion of a bouncing ball. By recording the position and velocity as a function of time, we can calculate the gravitational potential energy and kinetic energy in order to investigate how each quantity changes throughout the ball's motion.

Some useful definitions:

- Kinetic energy: Energy associated with motion, described by $KE = \frac{1}{2}mv^2$
- Gravitational potential energy: Stored energy associated with location in a gravitational field, described by $PE_g = mgh$
- Elastic potential energy: Stored energy associated with stretching or compressing a spring or another spring-like material, described by $PE_s = \frac{1}{2}kx^2$

Objectives:

- Describe how the position vs. time and velocity vs. time graphs correspond to the observed motion in the video.
- Use data from the video to elucidate energy transformations that take place while the ball is in motion.
- Determine whether the ball transfers energy to its surroundings, and identify when energy transfer takes place.

Central questions:

- What forms of mechanical energy does the ball have throughout its motion?
- When does the ball exchange energy with its environment?

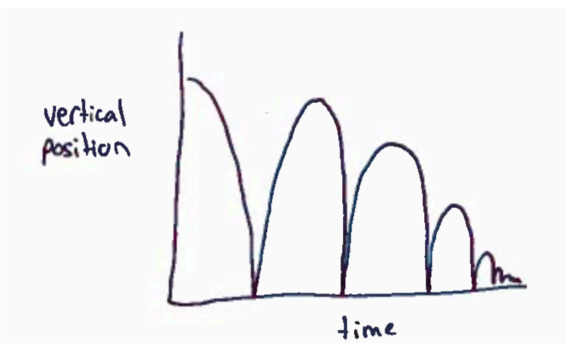
Predictions:

1. Download the "Bouncing ball" movie from Canvas under > Files > Movies for video analysis.
2. After watching the movie, predict what the vertical position versus time (y vs. t) plot will look like for the ball's center of mass while it is bouncing. Sketch your prediction plot below.

Predicted motion plot:

At this point in the quarter, students in our class were already familiar with position versus time graphs of motion in other contexts. Their predictions during this exercise provided a review of this skill and a jumping off point for analyzing graphs of mechanical energy, a topic that was less familiar to them.

Sample student prediction:



3. What forms of mechanical energy do you think the ball has at each of the following points throughout its motion? Explain your reasoning.
   a. The instant it is released from rest:

Sample student prediction:

It transforms from potential energy to kinetic energy

   b. As it falls toward the floor:

Sample student prediction:

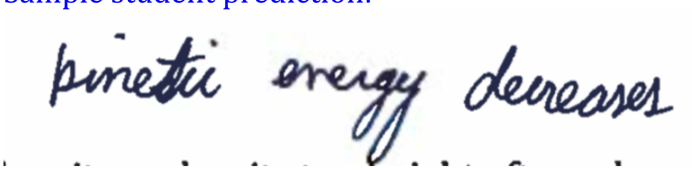
Kinetic energy increases

c. While it is in contact with the floor:

Sample student prediction:

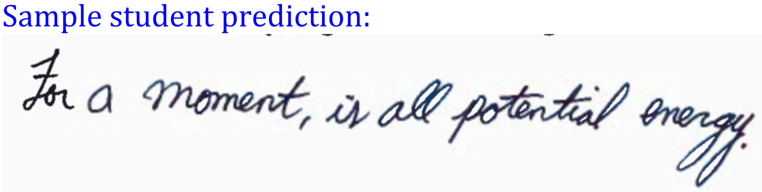
d. After it rebounds and is on its way up:

Sample student prediction:



e. When it reaches its top height after rebounding:

Sample student prediction:



Data collection: Position and Velocity

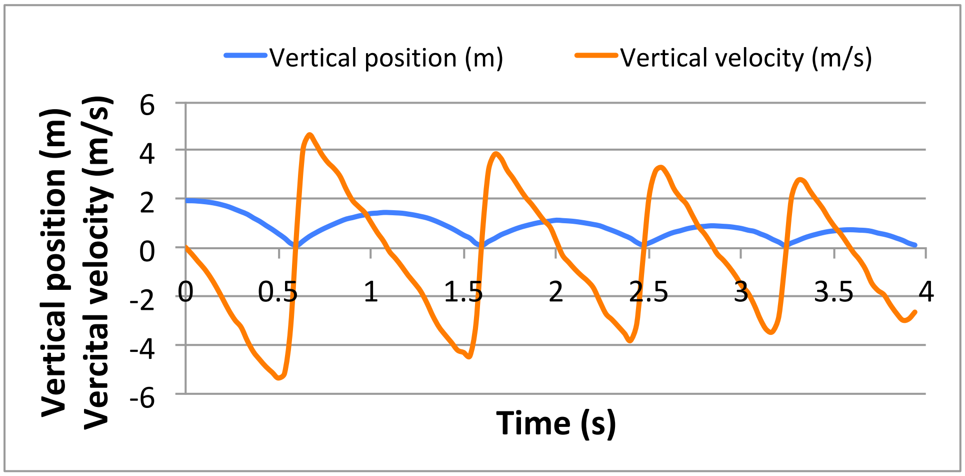
1. Open Tracker, go to "Import" and navigate to where you have saved the movie. If you're not sure where it is saved, try looking in the "downloads" folder.

Note: There are a number of video analysis software packages available that can be used for this activity. Our figures were produced using Tracker, an Open Source Physics (OSP) package designed for physics educational purposes, which can be downloaded for free from this site: https://physlets.org/tracker/. Video analysis can also be performed using the educational software package Logger Pro. We recommend introducing students to the basics of video analysis using the associated tutorials for the selected software.

2. Following the directions in the video analysis tutorial for collecting data from a movie, obtain the Vertical position vs. time (Y vs. t) and Vertical velocity vs. time (V_y vs. t) plots for the ball as it bounces at least 4-5 times.
3. Copy and paste your Time, Vertical Position (Y), and Vertical Velocity (Vy) data columns into *Excel*.

4. Prepare line plots of (Y vs. t) and Vertical velocity vs. time (V_y vs. t) in Excel and add axis labels. Ask if you need help with this. Print this graph, cut it out and tape it here:

A sample plot prepared by obtaining positional data with Tracker video analysis, and plotting the data in Excel:



5. In the next section, you'll use this data to calculate the ball's mechanical energy. First, let's examine the position and velocity graphs.
   a. In what portion of the ball's motion is the velocity positive?

      The velocity is positive when the ball is on the way up.

   b. In what portion of the ball's motion is the velocity negative?

      The velocity is negative when the ball is falling.

   c. Is the velocity every zero? If so, when does this happen?

      The velocity is zero when the ball is at the very top of its motion, the turn-around point before it begins moving back down.

   d. Can you explain how the velocity in each part of the motion described in (a-c) corresponds to changes in the ball's vertical position observed in the Y vs. time plot?

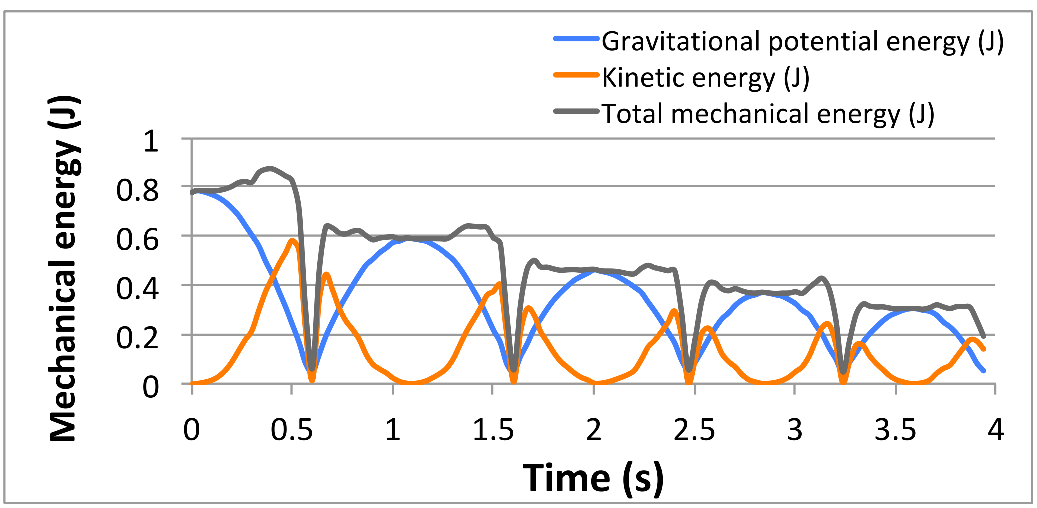
      As the ball moves up, the vertical velocity is positive. As the upward motion slows down due to gravity, the position versus time graph becomes less steep and the magnitude of the vertical velocity becomes smaller. When the ball is at the top of its flight, the vertical velocity crosses through zero. Then, as the ball falls and speeds up, the vertical velocity is negative and getting larger. The pattern repeats itself each time the ball hits the ground and rebounds, although the maximum height diminishes with each rebound.

Data analysis: Mechanical energy

1. You can calculate Gravitational potential energy and Kinetic energy directly from the raw data in the following way:
    a. Add a column in Excel labeled Gravitational Potential Energy (J). In the first cell, enter the formula "=m*g*h", where m is the estimated mass of the ball, g is the gravitational acceleration constant $9.8 m/s^2$, and *h* is the current vertical elevation above the floor. Ask for help if you're not sure how to enter the formula into Excel. Once you've entered this formula, select the bottom right corner of the cell with your mouse and drag it down to make the formula fill down through all the other cells in the column.
    b. Add a column in Excel labeled Kinetic Energy (J). In the first cell, enter the formula "= 0.5*m*Vy^2", where m is the ball's estimated mass, and Vy is the vertical velocity. As before, select the cell and drag down to fill in for other rows.
    c. Add a column in Excel labeled "Sum of Gravitational Potential + Kinetic Energy (J)". In the first cell, enter a formula that adds the current values of Gravitational Potential Energy and Kinetic Energy from the adjacent columns. As before, select the cell and drag down to fill in the formula for other rows.

2. Make a line plot that shows the <u>Gravitational Potential Energy vs. Time</u>, <u>Kinetic Energy vs. Time</u>, and <u>Sum of Gravitational + Kinetic vs. Time</u> all together in the same figure. Add appropriate vertical and horizontal axis labels, and include a legend that identifies each data set. Print this graph, cut it out and tape it here:

A sample plot prepared by obtaining positional data with Tracker video analysis, and plotting the data in Excel:



3. On your printed graph of mechanical energy, label by hand some time points corresponding to each of the situations described below (label as a, b, c, etc). For each one, describe here what is happening with the gravitational potential energy and the kinetic energy. (For example, "Gravitational potential energy is [increasing/decreasing/zero], Kinetic energy is [increasing/decreasing/zero]".

    a. As it falls toward the floor:

       Gravitational potential energy is decreasing. Kinetic energy is increasing.

    b. While it is in contact with the floor:

       Gravitational potential energy and Kinetic energy are both approximately zero. The energy must have transformed into some other form at this point. We can speculate that some of the energy is stored in the ball as elastic potential energy, and some may have transferred to the environment.

    c. After it rebounds and is on its way up:

       Gravitational potential energy is increasing. Kinetic energy is decreasing.

    d. When it reaches its top height after rebounding:

       Gravitational potential energy is at a local maximum. Kinetic energy is zero.

4. During which parts of the ball's motion (if any) does the <u>sum</u> of gravitational potential energy and kinetic energy stay relatively constant?

   The sum of gravitational potential energy and kinetic energy stay relatively constant whenever the ball is not in contact with the ground.

5. During which parts of the ball's motion (if any) does the sum of gravitational and potential energy change significantly? Where do you think the energy is going during these times?

   When the ball contacts the ground, the sum of gravitational potential energy and kinetic energy is close to zero. The energy must have transformed into some other form at this point. We can speculate that some of the energy is stored in the ball as elastic potential energy, and some may have transferred to the environment through heat dissipation or the formation of sound waves.

6. How does the total mechanical energy (gravitational + potential) while the ball is in the air change from one bounce to the next?

   After each time the ball impacts the ground, it rebounds with a smaller amount of total mechanical energy.

7. Based on your data and your answers to the discussion questions, write a short paragraph summarizing energy transformations and energy transfers that take place for a bouncing ball.

   When the ball is in the air, acted on by gravity, an energy transformation takes place in which the ball's kinetic energy transforms to gravitational potential energy on the way up; then the gravitational potential energy transforms to kinetic energy as the ball falls back toward the ground. When the ball hits the ground, some of its kinetic energy transforms into elastic potential energy as the ball deforms, making it possible to bounce upward again. The decrease in total mechanical energy with each rebound suggests that the ball transfers some of its energy to the environment each time it hits the ground.

For analyzing student dialogue, teachers may choose to utilize a Quantitative Literacy Assessment Rubric (Boersma et. Al)

Boersma, S., Diefenderfer, C., Dingman, S. and Madison, B. 2011. Quantitative reasoning in the contemporary world, 3: Assessing Student Learning. Numeracy, 4 (2)., https://scholarcommons.usf.edu/cgi/viewcontent.cgi?article=1080&context=numeracy (accessed February 28, 2020).