Objective
Illustrate how forces can do positive work, negative work, or no work on a body and how this tends to increase, decrease, or not change the speed (thus the kinetic energy) of the body.

Summary
Be ready. This lab involves a lot of work and energy! But you will be able to exert some power. (Sometimes freshmen believe they have very little power. We'll see in Task 3.)

From an engineering mechanics point of view you do no work unless you move an object through some distance. (Would you pay a mover to just push on your piano and not change its location? Or just to sit on the piano bench?) What's more, in calculating work we are only interested in those forces which tend to move the body along its path of motion, i.e., forces which are tangent to the path, since our objective is to move the body and possibly change its speed. However the values of forces which are tangent to the path, such as kinetic frictional forces, can depend on other forces normal to the path; these normal forces do no work on the body but affect values of kinetic frictional forces. Therefore it is still necessary to draw a complete FBD of the body before attempting to determine the work of the various forces acting on the body as it moves along some path.

Using Newton's Second Law of Motion, we have shown that the work of all forces acting on a body as it moves from position 1 to position 2 can cause the kinetic energy (and thus the speed) of the body to increase, decrease, or not change. Our equation relating this is

$$\Delta T = T_2 - T_1 = \sum \Delta U = \sum F_x \cdot ds = \int \sum F_i \cdot ds = \frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2$$

Note forces acting on the body in the direction of motion of the body do positive work and try to increase the speed of the body, those opposing the direction of motion do negative work and try to decrease the speed, and those acting perpendicular (normal) to the instantaneous direction of motion do no work and do not act to change the speed.

Once you understand the development of expressions to determine the work of various forces, it is convenient to memorize a few cases we see over and over as indicated below.

A) Work done on a body by a constant gravitational force as the body moves from position 1 to position 2.
$$U_{W,1\to2} = -mg(h_2 - h_1)$$
$h$ must be positive upward for this equation to be valid

B) Work done on a body by an elastic (linear) spring as it moves from position 1 to 2.
$$U_{SP,1\to2} = -\frac{k}{2}(x_2^2 - x_1^2)$$
$x$ = amount of stretch or compression in the spring

C) Work done on a body by a constant kinetic frictional force as the body slides from position 1 to position 2.
$$U_{f,1\to2} = -f_c(s_2 - s_1) = -\mu_k N_c (s_2 - s_1)$$
$U_f$ is always negative. $N_c$ must be constant for this equation to be valid.
Procedure and Analysis

Task 1. Determine the Stopping Distance for an Object Sliding on the Track

An object released from rest at position A shown below will accelerate down the track provided the maximum static frictional force $f_{\text{max}} = \mu_s N = \mu_s mg(\cos \theta)$ is less than the component of the weight $mg(\sin \theta)$ acting parallel to the track. Do you agree? Of course once the body begins to slide, the kinetic frictional force is $f_k = \mu_k N = \mu_k mg(\cos \theta)$. Once the object reaches the horizontal portion of the track it will decelerate until its velocity is reduced to zero. Why?

a) Take measurements to determine $H$, $L_{AB}$, and $\theta$. Your lab instructor will tell you the average experimentally determined coefficient of kinetic friction between the object and the track. (How did we determine this? Remember our lab where we determined values for the coefficients of static and kinetic friction between two objects?) You can measure the mass of the object if you wish, but you do not need it to calculate the distance $L_{BC}$, as only $\mu_k$ affects how far the object will slide for the set-up shown.

b) Using the principle of work/kinetic energy and your values from part (a), predict the speed of the object $v_B$ as it passes position B. Assume the track is straight and flat between locations A and B and between B and C, although there is a curved transition to the horizontal track in the region of B. Is the gravitational force doing positive or negative work, and is it acting to increase or decrease the speed? How about the frictional force?

c) Now, using the principle of work/kinetic energy calculate the distance $L_{BC}$ the object slides on the horizontal track before coming to rest. Is the gravitational force doing any work on the object as it slides on the horizontal portion of the path? Is it causing the speed to change on this portion of the path?

d) Release the object at position A and record the distance $L_{BC}$ the object slides before coming to rest. Repeat several times. How do the experimental values compare to the calculated value? Why might there be some small variation in the experimental values and why might they not agree exactly with the predicted value?

e) Since both work and kinetic energy are scalars rather than vectors, we can add algebraically the work of all forces from A to B to the work from B to C and set this equal to the sum of the kinetic energy changes from A to B and from B to C. Add (in symbolic form) the work terms from step (b) to those from step (c) and set them equal to the sum of the changes in kinetic energy terms from steps (b) and (c). Then substitute in the given information and solve for $L_{BC}$. Note this gives you a quick solution for $L_{BC}$, but $v_B$ is not determined using this method.

f) (At home?). Redo the calculations of parts (b) and (c) using the direct form of Newton's Second Law of Motion ($\sum F = ma$) and the fact that $a$ is constant from A to B, and is a different constant from B to C. Do either your FBDs or answers change from those in parts (b) and (c)? Absolutely not! You are only changing your technique of solving the problem. In this problem the work/kinetic energy method is shorter since it does not involve the intermediate step of calculating the accelerations, and you even could have avoided calculating $v_B$ by solving $U_{A-C} = T_C - T_A = (1/2)m(v_C^2 - v_A^2) = 0 - 0 = 0$. 

![Diagram of the track with labeled distances and angles.]
Task 2. Determine the Height to Which the Tennis Ball Rises

The tennis ball is supported from the ceiling by one strand of a bungee cord. The ball is pulled down to the floor (position "1") and released. You are to determine the maximum height, H, (position "2") to which the ball rises before it starts back downward. The mass of the tennis ball is 58 g.

a) Assume the cord can be treated as a linear spring having a spring constant of 1.1 N/m. Determine the unstretched (free) length of the cord and the initial stretch, x_1, in the cord just before the ball is released at position 1. What will be the "final" stretch, x_2, in the cord when the ball is in position 2? You should also check our value for the mass of the ball.

b) Draw a FBD of the ball just after it is released from position 1, determine the work of the cord and of the gravitational force \( W \) on the ball as it rises to its maximum height, H, and set this equal to the change of kinetic energy of the ball from 1 to 2. Solve for the height H.

c) Now do the experiment and compare your predicted value of H to the experimentally determined value. Why might not the values be exactly the same?

Task 3. Determine the Average Power Developed to Raise a Weight

Two systems of weights, pulleys and cords are shown below. The "10 lb" weights (including pulley in system B) each weigh approximately 11lb. CAUTION: Do not let the weights fall to the floor while either raising or lowering the weights.

a) Record the time it takes you to raise the weight A a known height, H, above the floor by pulling down on the cord. Carefully lower the weight back down to the floor.

b) Determine the work in raising the weight and the average power expended. Calculate the power in ft lb/sec; convert it to horsepower and to watts using 550 ft lb/sec = 1 hp = 746 W.

c) Repeat parts (a) and (b) for weight B. Note that you have to pull the cord twice as far to raise the weight B the same distance as you raised weight A, but did you produce any more work or any more power? Discuss.

d) If you were a horse and could only produce the power you calculated above, do you think you'd end up in the glue factory? (Maybe you'd have a benevolent owner.)