SCOPE, SEQUENCE, and COORDINATION

A National Curriculum Project for High School Science Education

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Student Materials

Learning Sequence Item:

1026

Qualitative Examples of Conservation of Mechanical Energy

January 1997
Adapted by: Stephen Druger

Contents

This micro-unit was adapted by **Stephen Druger** (Northwestern University, Evanston, Ill.)

Student Sheet

Science as Inquiry

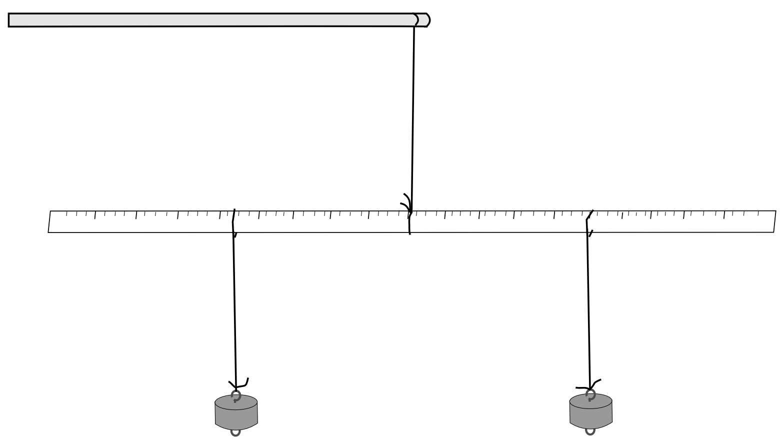
The Principle of the Lever

How a simple machine can make work easier

Overview:

Almost everyone is familiar with the seesaw popular with young children. But have you ever considered what principles of physics are involved in how it works, and how many practical applications these physics principles have in everyday use? In this activity, we examine the way a rigid bar (a lever), supported and free to rotate about a point, can be used to change how much force is being exerted, and we examine what rule determines the force it produces.

Procedure:



Attach a string at exactly the 50-cm mark (the midpoint) of the meter stick so it can be used to suspend the meter stick horizontally. A piece of tape may be useful in holding the string fixed at the desired location. Hang equal masses of about 30 g on each side of the meter stick, and adjust their positions so that the stick balances horizontally as illustrated.

This will work best if you locate one of the masses at the 25-cm mark and secure it in position with a piece of tape, and then adjust where the other mass must hang. Record the amount of mass on each side and its location measured as a distance from the point of support (at the 50-cm mark). Next, increase the mass fixed at the 25-cm mark to 60 g and again find where the other mass must be placed for the stick to balance. Record its distance from the point of support of the meter stick. Finally, increase the total mass at the 25-cm mark to 90 g, and reposition the other mass to balance the meter stick. In some cases, you might have to reposition both masses.

You may want to explore further by placing a prism shaped object *under* the meter stick so its edge supports the meter stick at the 50-cm mark. Place unequal masses (30 g and 60 g, or 30 g and 90 g) on *top* of the meter stick and try to balance it. See if you get the same results as when the masses were hanging from the meter stick.

Questions:

1. Did the distance the second mass needed to be from the center increase, decrease, or remain the same to balance the first mass when it was increased?

2. When the first mass was twice the second mass, by what factor did the force exerted by the first differ from the force exerted by the second? By what factor was the distance of the first mass from the point of support different from the second distance? How about when the first mass was three times as large as the second?

3. What general rule does this suggest about how the force on one side of the meter stick (pushing down) is related to the resulting force (pushing up) on the other side in terms of distance from the point of support? Try to express your answer in a form that could be used to calculate the numerical value of the force pushing up on one side in terms of the force applied downward on the other side.

4. When the masses are arranged so that the 30-g mass balances the 60-g mass, if the stick is tilted slightly so that the 60-g mass moves down a small distance of 0.1 cm, how far would the 30-g mass have to move up on its end of the meter stick? Use a diagram as needed to explain your answer.

5. How does this activity and your answers thus far explain how a pair of pliers can exert such a strong force? Use a diagram to explain your answer.

6. Assume reasonable numerical values for the lengths involved in a pair of pliers and for the force you might apply by hand and calculate the force that would result, in order to illustrate how the force is increased at the shorter end of the pliers.

7. If your much younger brother wants to “outweigh” you on a seesaw and get it to tilt in his favor, and you’re in a generous mood and want to let him succeed, how would you and he have to position yourselves on the seesaw to accomplish this?

Science as Inquiry

Block and Tackle

Energy and work relations for a simple machine

Overview:

In this activity you’ll examine the work and energy involved when a force is exerted to move an object through some specified distance. Two systems are examined—a mass hanging from one pulley and a mass suspended by a system of two pulleys. You will also see how a simple machine consisting of a rope and a set of pulleys can be used to lift heavy objects.

Procedure:

First hold the spring balance upside down, in the position it will be used for other measurements. If its reading is adjustable, adjust it to read zero in this position; otherwise, note the reading and, if not zero, use it to correct other force measurements made with the spring balance held this way.

Suspend a mass on one end of a string hanging over a pulley with the spring balance at the other end of the string, as shown in Figure 1. Measure the force it takes to move the mass slowly through a distance of 10 cm, recording the force and the distance moved by the spring balance.

Next, use the double-pulley arrangement shown in Figure 2. Again measure the force that must be applied by the spring balance and the distance through which it must move in order to lift the hanging mass a distance of 10 cm.

Figure 1

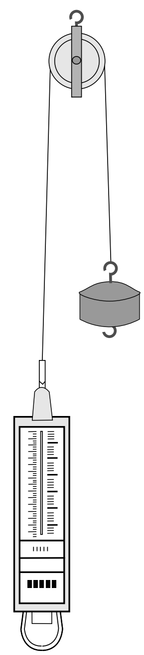
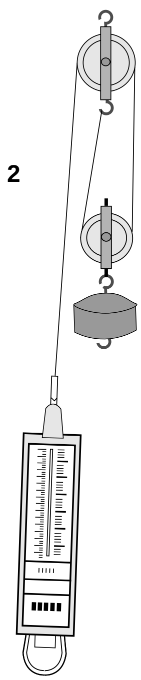


Figure 2



Questions:

1. How did the force in the one-pulley arrangement compare with that for two pulleys?

2. How did the distance the spring balance had to move in the first case compare with the distance in the second case?

3. If all the work done in lifting the object simply went into potential energy, so that the change in potential energy of the hanging mass in this case equaled the work done in lifting it, how did the work done compare in the two cases? How do you know this must be true without having to do any calculation?

4. What did the work that produced the change in stored energy?

5. How did the measured force times distance for the spring balance compare in the two cases?

6. In what ways, both in this activity and any other case you can think of, would it seem reasonable that the change in energy in lifting an object, or the work done, would be the force multiplied by the distance through which it acts?

7. Calculate for both pulley arrangements the force on the spring balance multiplied by the distance it moved, expressing your answer in appropriate units.

8. Do the results of this activity in themselves prove that the average force in moving an object multiplied by the distance it moves is the only possible definition for the work done, or do they show that such a definition is merely consistent with what you observed? Explain or justify your answer.

9. Many simple machines are based on applying a force to move levers or pulleys or ropes through a certain distance in order to produce a force that moves an object through a different distance. Assuming that no energy is lost to friction in such a machine, what general relation would you expect between the forces and distances, and why?

Science as Inquiry

On the Fast Track

If it rolls downhill, how far uphill does it roll back?

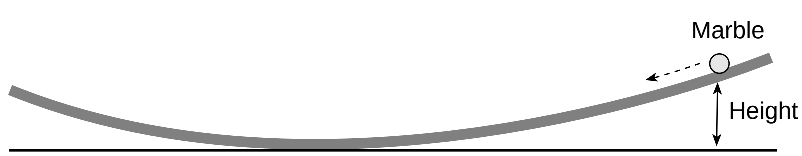
Overview:

Suppose an object such as a marble starts rolling down a smooth curved track that rises up on the other end. If you wanted to find how its speed varies at each instant, and just how far it would roll back up the other end of the track before stopping, you could in principle consider the forces acting and apply Newton's laws. In practice, that would usually lead to a complicated mathematical problem whose solution would be reasonably difficult. In this activity you will try exactly the experiment just described to see if there is some general principle that predicts in a simple way, without having to solve for all the details of motion, how far the marble can move.

Procedure:

Bend the plastic track so that it rises at both ends, more sharply on one side than on the other. Use whatever nearby objects are handy for supports so the track will not move when the marble rolls on it. Hold the marble at rest at one end of the track and release it to roll down the track. Note the location where the marble starts, the location where it comes to a stop on the far end, and the location to which it returns on the near end. Then use a ruler to measure the height at each of these locations. Average the two heights on the near side (the starting height and the concluding height) to compare with the height on the far side where the marble stopped to reverse direction.

Repeat the process for different starting positions and somewhat different track shapes.



Questions:

1. Based on the data, do you see any particular relationship between the heights attained on the two ends of the track? (The height on the near end, where the marble starts, is to be taken as the average of the initial and final heights on that end of the track in each trial.)

2. As the marble rolls along the track, how does its speed appear to vary?

3. What are the forces causing it to change its speed? Show them in a diagram.

4. How does the stored energy from lifting the marble against the force of gravity compare on the two ends of the track, where the marble starts and where the marble stops instantaneously to reverse its direction? Why?

5. How does this compare with the stored energy (potential energy) associated with the height of the marble when it was moving in the middle of the track?

6. How did the energy of motion (the kinetic energy) of the marble compare in the three cases—when the marble was at its farthest point on one end, when it was at its farthest point on the other end, and when it was in the middle?

7. Knowing that the total energy stayed the same and that the potential energy increased with height, what would you conclude about how the kinetic energy compared at the middle of the track and at each end? Why?

8. How did the speed vary as the marble moved at different heights along the track? How can you explain this in terms of how the potential energy varied with height, how the kinetic energy was related to the speed of the marble, and how the total energy did or did not vary?

9. How does this apply in determining the speed of a roller coaster at each location along the track, if you can disregard any energy lost in doing work against friction?

Science as Inquiry

Getting into the Spring of Things

How far does an object move when pushed off a table by a spring?

Overview:

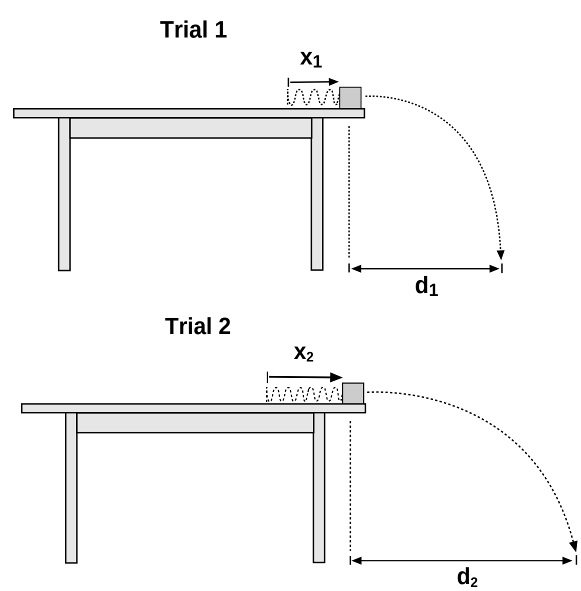
If you have ever thrown a baseball or football, you have noticed that there is a connection between the amount of force you exert and the distance the ball goes before striking the ground. There are other factors that determine the distance the ball travels, such as the angle upwards at which it is thrown. In this activity we examine the process of launching a projectile with a spring and see what it has to do with energy being converted from one form to another. We consider especially what the energy imparted has to do with the distance the object travels before reaching the ground, and, most importantly, we see what this implies about how the energy of motion, the "kinetic energy," depends on how fast the object moves.

To accomplish this, we use a spring to fire an object horizontally from the edge of a table using different degrees of compression of the spring. We then examine how the distance traversed before reaching the ground is related to how far the spring was compressed. Then we analyze how the relationship between spring compression and distance can be explained by the idea of stored (or "potential") energy in the spring being changed into energy of motion (or kinetic energy).

Procedure:

Clamp the spring to the top of the work table near the edge, so that after being compressed and released it will propel the block forward off the edge of the table. The spring could be the plunger of a ballistic cart, or it could be a hacksaw blade clamped into position. Use a plumb line to mark off on the floor the position directly beneath the edge of the table. Then measure the distance through which the end of the spring moves by being compressed.

Abruptly release the spring to knock the block off the table and record the horizontal distance from the edge of the table to where the block hits the floor. Repeat for different compressions of the spring, measuring the compression of the spring and the distance the block traveled.



Questions:

1. What general connection do you observe between the degree of compression of the spring and the distance through which the block moves horizontally before hitting the floor?

2. Evaluate the ratio *d/x* for each trial, where *d* is the distance from the edge of the table to where the block strikes the floor and where *x* is the compression of the spring (measured as displacement from the end of the uncompressed spring). What pattern, if any, is noticeable in these results?

3. The relationship you should have observed in answering the previous question is a specific result for this specific experiment, but there are general principles of physics that would lead you to expect this result. To get at these principles, first take a close look at the spring balance, which basically is just a spring that exerts more force the more it is stretched. (The same is true for a spring that is compressed.) What do you notice about the spring balance and the markings on it that tell you whether the force exerted by the spring is proportional to how far it is stretched, to the square of how far it is stretched, or to the square root of how far it is stretched?

4. How then would you expect the average force exerted by the spring throughout its motion on decompression to be related to the distance through which it was originally compressed (as measured by the distance x that it was compressed)? Is it proportional to x, x^2, x^3, or what? What leads you to this conclusion?

5. The work done by the spring in moving the block ought to be the average force it exerts multiplied by the distance through which it pushes. Is the work done by the spring on the block then proportional to x, x^2, x^3, or what? Again, what leads you to this conclusion?

6. If the work done setting the block into motion depends on the compression of the spring, how then does the energy of motion of the block, its "kinetic energy," depend on the compression of the spring in this specific experiment?

7. Does the time it takes for the block to reach the ground depend on how fast the block was ejected by the spring? How do you know this?

8. If the block were traveling three times as fast initially, what does this imply about how much farther it would go before reaching the ground? Why?

9. Now, if the time to reach the ground is the same in all cases, and the distance *d* before reaching the ground is proportional to the spring compression x, what does this tell you about how the horizontal speed attained depended on the spring compression x? Were the two proportional to each other, was one proportional to the square of the other, or what? Explain your reasoning.

10. The initial kinetic energy of the block was the potential energy stored in the spring and depended on the compression in the way you already concluded. Since the speed attained depended on the spring compression *x* in the way you described, how then did the kinetic energy depend on the speed *v*? Specifically, are your experimental results consistent with kinetic energy being proportional to the speed, the speed squared, the square root of the speed, or what? Explain or justify your answer.

Student Sheet

Science as Inquiry/
Science and Technology

The Rube Goldberg Invention Kit

Build your own energy conservation machine

Overview:

At this point you've seen how in many simple machines forces can be changed by changing the distances over which they act, with the work done being the same. Do the same work by pulling or pushing over a longer distance, and it will take less average force.

Also, in simple machines energy can change form. For example, the energy stored in a spring can be converted into the energy of lifting an object. It can also be transferred from place to place. In addition, potential and kinetic energy can change one into the other, as, for example, when a block is ejected from the table by releasing a compressed spring. But again the total energy is seen to stay the same.

Many devices combine pulleys, levers, and different gears all working together to accomplish some purpose. But just how complicated can these combinations be? A "Rube Goldberg" device is an invention, usually created humorously, designed to accomplish some simple specific task in the most complicated way possible.

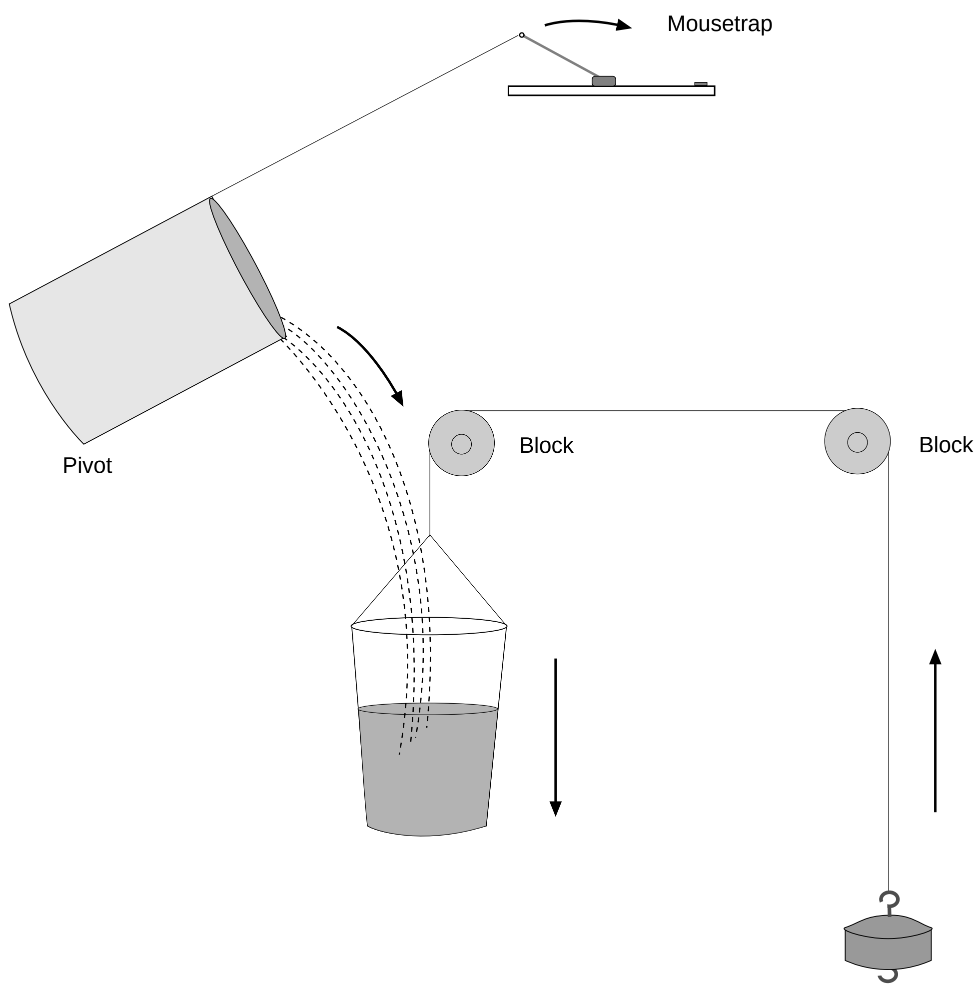
The goal of this activity is to create such a "device" to accomplish the simple task of lifting a weight in the most complicated way you can devise that actually works, and then to analyze the transformations in energy that occur at each step of its operation.

Procedure:

This activity is an exercise in creativity as well as physics. You will be given a set of assorted springs, levers, mousetraps, etc. In addition, you can use anything else (within reason) that you find available nearby. Design a device that will accomplish the simple task of lifting a weight when you do nothing more than touch a spring release or briefly tug on a string. The device should have at least five energy transformations, and the challenge is not only to design it but to build it and show that it works.

An example of a possible Rube Goldberg device is shown on the following page. When the spring on the mouse trap is released by touching a pencil to it, the effect is to lift the weight. Note that in the example given the initial step did not need to be release of a spring. The device could have involved tugging a string by hand to spill the water or dropping a weight on the mousetrap.

See what you can create that really works and that uses more steps than the device shown.



Questions:

1. Make a list of all the steps in the operation of your device that involve a transformation of energy from one form to another or from one simple machine to another.

2. For each step, describe what energy transformations are occurring and how they occur.

3. Identify the source of the energy in each case.

4. In the device illustrated here, a mere tug on a string attached to the mousetrap results in lifting a weight through a considerable distance. This required work. Identify the source or sources of the energy that made this work possible.

Science as Inquiry

What Did All That Work Accomplish?

Why there is an energy crisis

Overview:

If energy is conserved, it is reasonable to wonder how there can possibly be an energy crisis. Certainly there is plenty of energy all around us, and if energy can be neither created nor destroyed, how can there be a shortage of it? Doing work involves changing one form of energy into another. When we do work by compressing a spring, we can then let the spring do work in pushing up a weight, converting potential energy of the compressed spring into gravitational potential energy. Or we could allow the compressed spring to push an object and set it into motion so that it has kinetic energy. If that were all there is to it, we could just keep reclaiming energy by converting it from one form to another and never need to do anything as drastic as burning gasoline to set a car into motion.

This activity concerns a typical case in which work is done and energy clearly has been pumped into the system by applying a force to lift an object, and yet the system at the end looks the same as at the beginning. Specifically, we repeatedly lift and drop a quantity of lead shot within a cardboard tube by quickly turning the tube top to bottom. Certainly lifting the shot requires doing work, meaning that energy is supplied to the system. The question we seek to answer is, “Where did the energy go?”

Procedure:

Weigh out 2.2 kg of lead shot and place them in the cardboard mailing tube. Sealing the tube with the solid stopper, use a meter stick to measure the *average* distance through which the shot would lift and fall if the tube were quickly inverted top to bottom. Now, substituting the stopper with the inserted thermometer, carefully bring the lead shot into contact with the thermometer for an initial temperature reading.

Replace the stopper and thermometer with the solid stopper. Now, start the twisting action! Quickly and repeatedly invert the tube, exactly 100 times, so that the lead shot fall from top to bottom each time. Then carefully measure the temperature again. Try not to destroy the thermometer!

Questions:

1. Describe what interchanges between kinetic and potential energy occur and their relation to work done on the lead shot during the process of inverting the tube until the point when the shot begin to fall.

2. How does the potential energy of the lead shot change as they fall? What happens to their kinetic and potential energies and to their total energy during this process up to the point where the shot are about to hit the bottom of the container?

3. What change did you observe in the lead shot after inverting the tube 100 times?

4. Work has been done on the system, but the lead shot are, in the end, located about where they were at the beginning. What do your results suggest has happened to the energy?

5. Is this energy in a form where you could easily use it to move the lead shot back up to the top of the tube? Why or why not?

6. It takes 0.038 calories of heat to raise the temperature of 1 g of lead 1 K (1K = 1 Celsius degree). From your data, calculate the work (in Joules) that was done on the system, then calculate the number of calories of heat that would have been needed to accomplish the same temperature change. By equating the two results, determine what amount of energy, according to your data, corresponds to 1 calorie of heat.

7. Are you doing work by walking a distance of 2 km on level ground? Explain the reasoning that leads you to your answer.

8. If your answer to question 7 was that walking 2 km on level ground really involves work, explain what happened to the energy in doing the work. If your conclusion is that it did not involve work, explain why it seems to take a lot of effort to walk that distance.