Name Period Date

# 23. Work and Mechanical Advantage

***Simply Forceful - The Sequel***

## Driving Question

What happens to the amount of force needed to move an object when simple machines are used in combination?

## Materials and Equipment

***For each student or group:***

- ☐ Data collection system
- ☐ Force sensor with hook
- ☐ Meter stick or ruler
- ☐ Balance
- ☐ Tinker Toys™ or other building materials
- ☐ PAScar or other cart or toy car
- ☐ Pulleys
- ☐ String

## Safety

Add this important safety precaution to your normal laboratory procedures:

- Do not apply a pushing or pulling force greater than 50 newtons to the force sensors (doing so will damage the sensor).

## Thinking about the Question

In the previous activity, Simply Forceful, you saw that using a simple machine such as a pulley can change the amount of input force necessary to move an object. You also discovered that a pulley can change the direction in which the input force is applied without changing the amount of input force.

As you know, there are only six simple machines, but they serve as the building blocks for almost all other machines. People invented these simple machines to help make work easier by changing either the direction or amount of input force necessary, or both. In physical science, work means using an input force to move an object.

In this activity, you will be working with two different simple machines connected together to determine how they change the direction or the amount of force necessary to move an object. You will also investigate what happens to the amount of necessary force when you change the distance through which the force is applied.

Discuss with your lab group members the way that different arrangements of pulleys change the direction or the amount of force, or both, required to lift an object off the table. Discuss in your group how ramps work, what type of simple machine they are, and how you might construct one using the materials provided in your class.

## Sequencing Challenge

☐ **The steps below are part of the Procedure for this lab activity. They are not in the right order. Determine the proper order and write numbers in the circles that put the steps in the correct sequence.**

| ◯ | ◯ | ◯ | ◯ | ◯ |
|---|---|---|---|---|
| Predict how much force will be necessary to lift a cart off the table. | Make sure each lab group member is aware of safety rules and procedures for this lab. | Compare the data for fixed and moveable pulleys. | Record force data as you pull the cart up the ramp. | Construct a ramp out of available materials. |

## Investigating the Question

☐ **Note:** When you see the symbol "�" with a superscripted number following a step, refer to the numbered Tech Tips listed in the Tech Tips appendix that corresponds to your PASCO data collection system. There you will find detailed technical instructions for performing that step. Your teacher will provide you with a copy of the instructions for these operations.

### Part 1 – Making predictions

1. ☐ Write your predictions for the following:
   a. What amount of force will be necessary to lift a cart off the table?
   b. How will the amount of necessary force change if the cart is pulled up a ramp to the same height?
   c. What effect will there be on the amount of force necessary to pull the cart up the ramp if one or more fixed or movable pulleys are used?

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2. ☐ In the space below, sketch a force versus time graph that reflects your predictions.

**Part 2a – Lifting straight up against gravity**

3. ☐ Start a new experiment on the data collection system. �(1.2)

4. ☐ Connect a force sensor to the data collection system. �(2.1)

5. ☐ Display Force on the y-axis of a graph with Time on the x-axis. �(7.1.1)

6. ☐ Hold the force sensor with its hook down, and press the “zero” button.

7. ☐ Gently attach the force sensor’s hook to your cart, using a piece of string.

8. ☐ Begin data recording. �(6.2)

9. ☐ Holding the force sensor steady, lift the cart until it is off the table and hold it in place until the force data stabilizes.

10. ☐ Stop data recording. �(6.2)

11. ☐ Observe your graph of force versus time. What do you notice about your data?

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**Part 2b – Using a ramp**

12. ☐ Using materials provided, construct a ramp for your cart to travel on. Test the cart on the ramp to be sure it rolls well. How might a poorly-rolling cart affect your force data?

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13. ☐ Measure the length and height of the ramp. Record these measurements below:

Ramp Length: __________ M

Ramp Height: __________ M

14. ☐ Place a force sensor flat on the ramp and press the “zero” button. This tells the sensor that it is measuring force parallel to the ramp. When is it important to zero the force sensor in experiments?

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15. ☐ Place the cart at the lower end of the ramp, ready to roll.

16. ☐ Gently attach the cart to the force sensor's hook, using a piece of string.

17. ☐ Begin data recording. �(6.2)

18. ☐ Pull on the force sensor slowly and steadily to roll the cart up the ramp, continuing as far up the ramp as you can pull it.

19. ☐ Stop data recording. �(6.2)

20. ☐ Observe your graph of force data. You may need to rescale your graph to see all of your data. �(7.1.2) Note below any patterns or observations you see.

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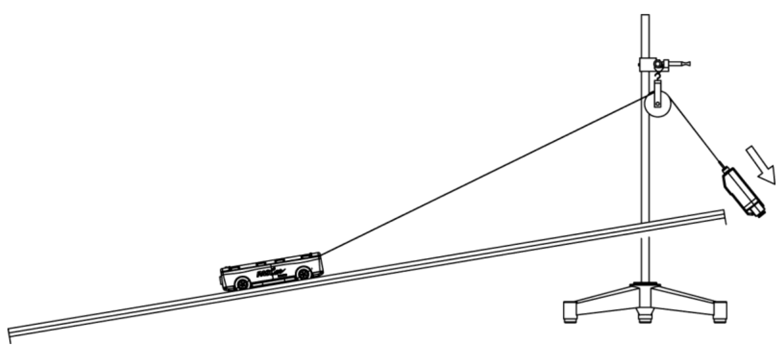
**Part 3 – Using pulleys and a ramp**

21. ☐ Using materials as you did in the Simple Machines and Force activity, devise a fixed pulley system. You will pull the cart up the ramp by pulling down on the force sensor.



22. ☐ Test your design to make sure it works as designed. Make adjustments if necessary.

23. ☐ Press the "zero" button while the force sensor's hook is pointing down.

24. ☐ Begin data recording. �(6.2)

25. ☐ Pull down on the force sensor slowly and steadily, to make the cart travel up the ramp.

26. ☐ Stop data recording. �(6.2)

27. ☐ Observe your graph of force data. �(7.1.3) You may need to rescale your graph to see all of your data. �(7.1.2) Note below any patterns or observations you see:

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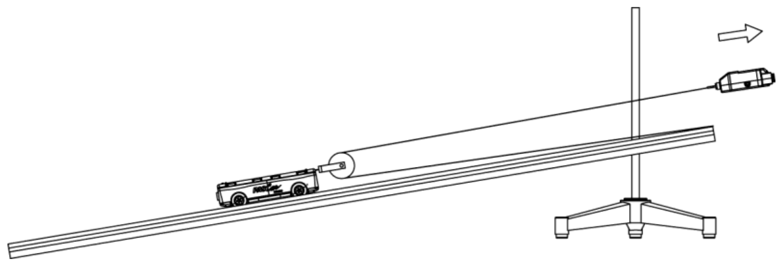
28. ☐ Again, using materials as you did in the Simple Machines and Force activity, devise a movable pulley system so that the pulley travels along with the cart. You will again pull the cart up the ramp by pulling on the force sensor in a direction parallel to the ramp.



29. ☐ Test your design to make sure it works as designed. Make adjustments if necessary.

30. ☐ Place the force sensor flat on the ramp and press the “zero” button.

31. ☐ Gently attach the string to the force sensor’s hook.

32. ☐ Begin data recording. �(6.2)

33. ☐ Pull on the force sensor slowly and steadily to roll the cart up the ramp.

34. ☐ Stop data recording. �(6.2)

35. ☐ Observe your graph of force data �(7.1.3) You may need to rescale your graph to see all of your data. �(7.1.2) Note below any patterns or observations you see:

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## Answering the Question

### Analysis

1. How did your predictions from Part 1 compare to the results in Part 2?

2. Sketch the graphs of force versus time from your experimental trials.

3. The ramp you constructed is an example of an inclined plane which changes the amount of input force you need to apply to lift the cart. The ramp's *mechanical advantage* tells the number of times it increases the force applied to it. The mechanical advantage of a ramp can be calculated from the following equation:

Mechanical Advantage = Length of Incline / Height of Incline

4. Using your measurements from Part 2, calculate the mechanical advantage of your ramp:

$$\text{Mechanical advantage} = \frac{\text{length of incline}}{\text{height of incline}} =$$

5. About how many times does your ramp multiply your input force on the cart compared to lifting the cart straight up to the same height?

6. When a force moves an object over a distance, we say that work is done on the object. When you pulled your cart up the ramp, how was work being done on the cart?

7. How did the fixed pulley change the amount or direction of input force that was applied to the cart?

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8. How did the movable pulley change the amount or direction of input force that was applied to the cart?

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9. The ramp and pulley system you constructed is an example of a *compound machine* – two or more simple machines working together. Although each simple or compound machine makes work easier, there is always a trade-off of some sort between how much force must be applied and the distance over which that force is applied. Look at your force data for the different combinations of machines as well as for lifting the cart straight up. What combination of simple machines resulted in the least amount of force necessary to move the cart off the table? Do your experimental results tend to agree or disagree with your calculations from questions 3 and 4? Explain your reasoning.

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## Key Term Challenge

☐ **Fill in the blanks from the randomly ordered words below:**

| | | | |
|---|---|---|---|
| newtons | compound machine | work | force |
| pulley | mechanical advantage | input force | inclined |
| ramp | | | |

1. The force applied to a machine is called the ________________.

2. A/an __________________________ is one made from two or more simple machines.

3. A force acting over a distance to move an object is known in physical science as ____________.

4. The SI unit used to measure the force is __________________ .

5. The ________________________________ tells us how many times a machine multiplies the applied force. It is a ratio of the input force to the output force.

6. Any push or pull exerted on an object, whether or not it causes the object to move, is known as a/an __________________ .

7. A simple machine known as a/an __________________ is made from a rope, a string, or a belt wrapped around a wheel.

8. A simple machine with a flat, sloped surface that makes it easier to lift a heavy load by using less force over a greater distance is known as a/an _____________________ .

9. A pulley that has a mechanical advantage of 3 multiplies the ____________________ by three times that amount.