Mechanical Advantage of Pulleys – ID: 11568
By Irina Lyublinskaya

Time required
45 minutes

Topic: Work and Energy
- *Calculate the mechanical advantages and efficiencies of simple machines.*

Activity Overview
In this activity, students explore a single-fixed-pulley system. They vary the load and measure the force necessary to lift the load. They use these data to determine the mechanical advantage of the pulley system for each load. They then use simulations of more-complex pulley systems to extend their understanding of mechanical advantage.

Materials
To complete this activity, each student will require the following:

- *TI-Nspire™ technology*
- *Vernier Dual-Range Force sensor*
- *Vernier EasyLink™ or Go!® Link interface*

- *single pulley with clamp*
- *mass set with hanger*
- *string*

TI-Nspire Applications
Graphs & Geometry, Notes, Lists & Spreadsheet, Data & Statistics

Teacher Preparation
Before carrying out this activity, students should be familiar with the definition of mechanical advantage and the equations that can be used to calculate it.

- *The string used should be thin enough to easily fit through the pulley. Clamp or otherwise attach the pulley to a solid surface so that it cannot move.*
- *If a hanging mass set is not available, students can use other masses in the activity. They should use string or another material to attach the masses to the pulley system.*
- *The screenshots on pages 2–7 demonstrate expected student results. Refer to the screenshots on page 8 for a preview of the student TI-Nspire document (.tns file). Pages 9–11 contain the student worksheet.*
- ***To download the .tns file and student worksheet, go to education.ti.com/exchange and enter "11568" in the search box.***

Classroom Management
- *This activity is designed to be **student-centered**, with the teacher acting as a facilitator while students work cooperatively. The student worksheet guides students through the main steps of the activity and includes questions to guide their exploration. Students may record their answers to the questions on blank paper or answer in the .tns file using the Notes application.*
- *The ideas contained in the following pages are intended to provide a framework as to how the activity will progress. Suggestions are also provided to help ensure that the objectives for this activity are met.*
- *In some cases, these instructions are specific to those students using TI-Nspire handheld devices, but the activity can easily be done using TI-Nspire computer software.*

The following questions will guide student exploration during this activity:
- What is the relationship between effort force and resistance force when you pull a load in a single-fixed-pulley system with constant speed?
- What is the mechanical advantage of a single fixed pulley?
- Why is a single fixed pulley used to lift heavy loads?
- How can pulleys be used to increase mechanical advantage?

The goals of this activity for students are a) to observe and compare the magnitude and direction of the effort force and resistance force of a pulley system; b) to determine the mechanical advantage of a single-fixed-pulley system; c) to determine the reasons for using a single-fixed-pulley system; and d) to qualitatively explore other pulley systems. Students collect data on effort force for various loads in a single pulley system, analyze these data, calculate the mechanical advantage in each case, and make conclusions about the usefulness of the single pulley system. Then they use simulations to explore various constructions of single and double pulley systems and their mechanical advantages.

Problem 1 – Exploring a single-fixed-pulley system

Step 1: Students should set up a single-fixed-pulley system by attaching a pulley to a solid surface (such as the underside of a table). They should cut a piece of string approximately 100 cm long and make small loops on each end of the string. They should place the string around the pulley. Their setup should resemble the diagram to the right.
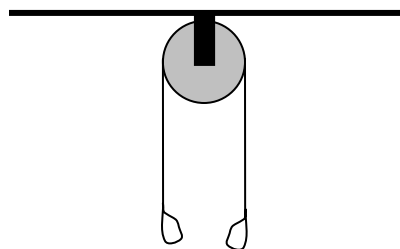

Step 2: Students will use a Vernier Dual-Range Force sensor to collect force data. Make sure the switch on the force sensor is in the ±10 N position. Students should connect the force sensor to the EasyLink interface (if students are using TI-Nspire handhelds to collect data) or to the Go! Link interface (if they are using TI-Nspire computer software to collect data). Students should not connect the EasyLink or Go! Link interface to their handheld or computer yet. Then, students should answer questions 1 and 2.

Q1. If you place a mass at one end of the string, what force will be required to lift the mass with constant speed?

A. *In the absence of friction, the force needed to lift the mass at constant speed is equal to the weight of the mass. If you wish, you may have students discuss the role of friction (between the string and the pulley and between the pulley and its axle) in the system.*

Q2. What forces act on the system in this case? Draw a force diagram for the system.

   A. *A sample force diagram is shown below.*
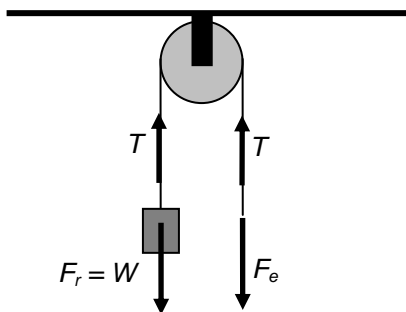
   Here T *is the force of tension,* F_r *is the resistance force (equal to* W*, the weight of the mass), and* F_e *is the effort force.*

Step 3: Next, students should open the file **PhyAct_11568_Pulley.tns**, read the first two pages, and then connect the EasyLink interface to their handheld (or the Go! Link interface to their computer). A force data collection display should appear.

Step 4: Students should select **Menu > Experiment > Display Data In > New Graphs & Geometry.** A new *Graphs & Geometry* page with a data collection box should be automatically inserted in the .tns file. (Note: When students connect the interface to their handheld or computer, a dialog box may appear asking them what type of application they want to insert the data collection box in. If this occurs, students should select *Graphs & Geometry* from the menu and click OK.)
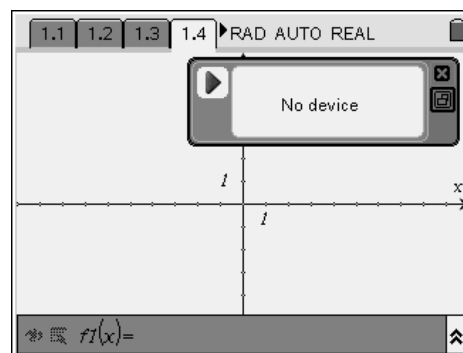

Step 5: Students should wait for the data collection display to stabilize and then zero the force sensor (**Menu > Sensors > Zero**). Then, they should place a 100 g mass on one end of the string and connect the force sensor to the other end of the string.

Step 6: Next, students should set up the data collection for **Events with Entry** mode (**Menu > Experiment > Set Up Data Collection > Events with Entry**). The "play" button (►) should be highlighted in the data collection box. If this is the case, students need only click (press ⌖) to begin data collection. If the play button is not highlighted, students should press (tab) until it is selected.

Step 7: Students should start the data collection and then pull downward on the force sensor to lift the mass up at a steady pace. Once the reading is stable, they should click on the Keep button (▤) to save the data point. Students will be prompted to enter a value in the event box. They should enter the mass attached to the string.

Step 8: Students should repeat the data collection four more times, adding 100 g to the mass on the end of the string during each trial. (The final mass should be 500 g.) Once the data have been collected, students should stop the data collection, close the data display box, and disconnect the EasyLink from the handheld (or Go! Link from the computer).
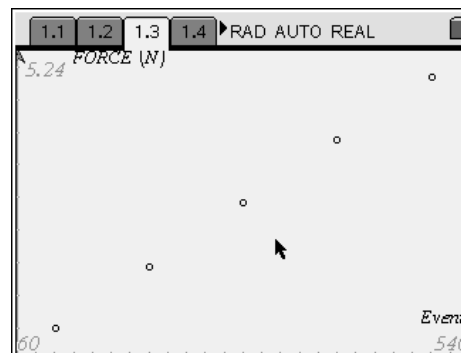
Step 9: Next, students should move to page 1.4, which contains a *Lists & Spreadsheet* application. Students will use this application to calculate the resistance force. Before they calculate resistance force, they should answer question 3.

 Q3. How would you calculate the resistance force for each trial?

   A. *The resistance force (F_r) is the weight of the attached mass. In order to calculate it, students should use the formula W = mg, where* m *is the mass in kilograms and* g *is acceleration due to gravity (9.8 m/s^2). Since the students' mass data are recorded in grams, they will need to divide the mass by 1,000 before multiplying it by 9.8.*

Step 10: Students should set column A equal to **dc01.event**, the data set containing the mass they recorded. They should then set column B equal to **dc01.force1**, the data set containing the effort force data they collected. They should label column A *mass* and column B *e_force*.

	mass	e_force	C	D
◆	=dc01.eve	=dc01.forc		
1	100.	0.984322		
2	200.	1.93799		
3	300.	2.92829		
4	400.	3.88794		
5	500.	4.85394		

B e_force

Step 11: Students should label column C *r_force*. They should then enter the expression **=a[]·9.8/1000** in the formula bar for column C and press ⏎. Column C should now display the resistance force for each trial. Students should study the data and then answer questions 4 and 5.

	mass	e_force	r_force	D
◆	=dc01.eve	=dc01.forc	=a[]*9.8/1(	
1	100.	0.984322	0.98	
2	200.	1.93799	1.96	
3	300.	2.92829	2.94	
4	400.	3.88794	3.92	

$$C \quad r\_force := \frac{a[\ ]\cdot 9.8}{1000}$$

Q4. Compare the effort and resistance force for each mass.

A. *The effort force (F_e) is the downward force applied by pulling on the force sensor. In each case, the magnitude of the effort force is equal to the magnitude of the resistance force (F_r), but the forces have opposite directions.*
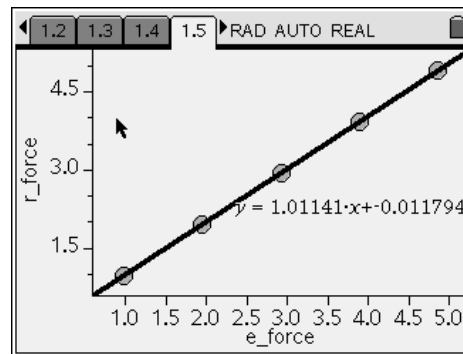
Q5. What is the mechanical advantage of this pulley system?

A. *The mechanical advantage is the ratio of the resistance force to the effort force. It is equal to 1 for a single-fixed-pulley system. Students' calculated data should follow this relationship.*

Step 12: Next, students will confirm their observations of mechanical advantage using a graph. They should move to page 1.5, which contains an empty *Data & Statistics* application. They should use this application to make a plot of *r_force* vs. *e_force*.
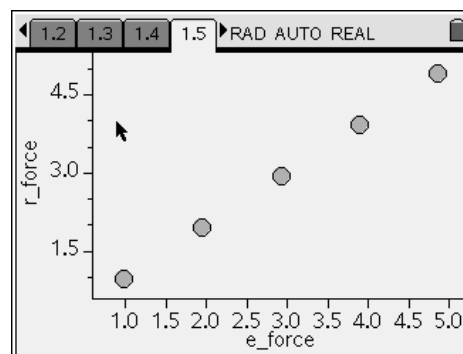
Step 13: Students' data should lie along a straight line. Students should use the **Regression** tool (**Menu > Analyze > Regression > Show Linear (mx + b)**) to find the best-fit line for their data. They should then answer questions 6–8.

Q6. Does this graph agree with your answer to question 5? Explain your answer.

A. *The best-fit line should have a slope of approximately 1. This slope is equal to the mechanical advantage of the pulley system, and it should agree with students' observations.*

Q7. What is the advantage of using a single fixed pulley to lift a load?

A. *A single fixed pulley changes the direction, but not the magnitude, of the force required to lift the load. Pulling downward is often easier than lifting upward, even if the force applied is the same.*

Q8. Can you think of a way to use a single pulley to produce a mechanical advantage greater than 1?

A. *Students' answers will vary. For a single pulley to have a mechanical advantage greater than 1, the pulley must be able to move. Furthermore, the pulley must be turned upside-down. Students will explore this type of system in the next problem.*

Problem 2 – Pulley system simulations

Step 1: Next, students should move to page 2.1, which shows a simulation of a single-movable-pulley system. Students should use the **Length Measurement** tool (**Menu > Measurement > Length**) to measure the lengths of the resistance force (downward vector) and the effort force (upward vector). They can change the effort force by dragging point *pull up* up or down; they can change the resistance force by dragging point *change load* up or down. You may wish to point out that, when they move the *pull up* point, the value that is displayed for load represents the resistance force the effort force produces. Similarly, when they move the *change load* point, the upward force value displayed represents the effort force require to lift that load. They should then answer questions 9 and 10.
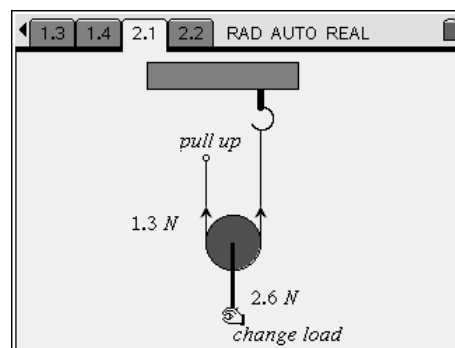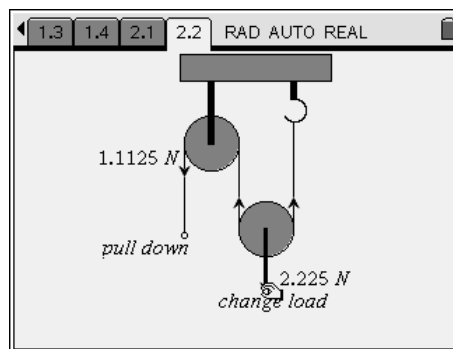
Q9. What is the mechanical advantage of this system? Explain your answer.

A. *Mechanical advantage is the ratio of resistance force to effort force. In this case, the lengths of the two vectors show that $2F_e = F_r$, so $\dfrac{F_r}{F_e} = 2$. The mechanical advantage of this system is therefore 2. The force diagram on page 2.1 illustrates that the tension (upward, or effort, force) on each string is equal to half the resistance force—that is, the weight of the load is distributed equally between the two strings.*

Q10. Do you think a single movable pulley would be easier or harder to use than the single-fixed-pulley system?

A. *Students' answers will vary. On the one hand, this system requires half as much effort force as the fixed-pulley system. On the other hand, it is generally much easier to apply a downward effort force than an upward force, so this system may be more difficult to use. This difficulty is compounded by the fact that the pulley itself moves.*

Step 2: Next, students should move to page 2.2, which contains a simulation of a two-pulley system that also has a mechanical advantage of 2. This system uses a single moving pulley in combination with a fixed pulley. This allows the effort to be applied downward, making the pulley system easier to use than the single-movable-pulley system on page 2.1. Students can change the effort force by dragging point *pull down* up or down; they can change the resistance force by dragging point *change load* up or down. Students should again measure the lengths of the resistance vector and the effort vector. They should then answer question 11.

Q11. What is the mechanical advantage of this system? Explain your answer.

A. *The resistance force is equal to twice the effort. The mechanical advantage of this system is therefore 2. If time and materials permit, you may wish to have students build pulley systems that resemble those on pages 2.1 and 2.2, collect force data for the systems as they did in problem 1, and confirm their answers to questions 9 and 11. If you wish, you may also have students explore the relationship between the distance the rope is pulled in each case and the distance the load moves. This can help them understand that simple machines do not reduce the amount of work done (i.e., if a smaller force is required, it must be applied over a greater distance).*

Mechanical Advantage of Pulleys – ID: 11568

(Student)TI-Nspire File: *PhyAct_11568_Pulley.tns*

Mechanical Advantage of Pulleys
**ID: 11568**

Name _____

Class _____

In this activity, you will explore the following:

- *the relationships between the effort force and the resistance force in a pulley system*
- *the mechanical advantages of various pulley systems*

In this experiment, you will observe and compare the magnitude and direction of the effort force and resistance force of a pulley system, determine the mechanical advantage of the pulley system, and infer the reasons for using pulley systems. You will also use simulations to explore various constructions of single- and double-pulley systems and their mechanical advantages.

Problem 1: Exploring a single-fixed-pulley system

Step 1: Set up a single-fixed-pulley system as shown in the diagram to the right. Attach the pulley to a rigid surface. Cut a 100 cm length of string, and make small loops in each end. Place the string around the pulley.
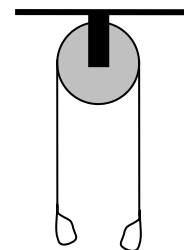
Step 2: You will use a Vernier Dual-Range Force sensor to collect force data. Make sure the switch on the force sensor is in the ±10 N position. Connect the force sensor to the EasyLink interface (if you are using a TI-Nspire handheld to collect data) or to the Go! Link interface (if you are using TI-Nspire computer software to collect data). Do not connect the EasyLink or Go! Link interface to your handheld or computer yet.

Q1. If you place a mass at one end of the string, what force will be required to lift the mass with constant speed?

Q2. What forces act on the system in this case? Draw a force diagram for the system.

**Step 3:** Open the file **PhyAct_11568_Pulley.tns**, read the first two pages, and then connect the EasyLink interface to your handheld (or the Go! Link interface to your computer). A force data collection display should appear.

Step 4: Select **Menu > Experiment > Display Data In > New Graphs & Geometry.** A new *Graphs & Geometry* page with a data collection box should be automatically inserted in the .tns file. (Note: If a dialog box appears asking what type of application you want to insert the data collection box in, select *Graphs & Geometry* from the menu and click OK.)
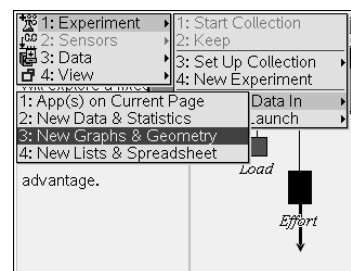
Step 5: Wait for the data collection display to stabilize, and then zero the force sensor (**Menu > Sensors > Zero**). Then, place a 100 g mass on one end of the string, and connect the force sensor to the other end of the string.

Step 6: Next, set up the data collection for **Events with Entry** mode (**Menu > Experiment > Set Up Data Collection > Events with Entry**). The "play" button (▶) should be highlighted in the data collection box. If this is the case, you need only click (press ⊙) to begin data collection. If the play button is not highlighted, you should press (tab) until it is selected.
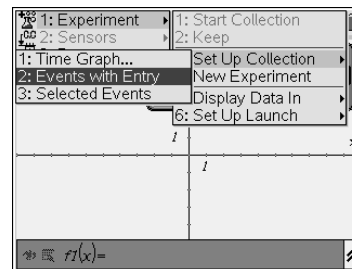
Step 7: Start the data collection and then pull downward on the force sensor to lift the mass up at a steady pace. Once the reading is stable, click on the Keep button (🖫) to save the data point. You will be prompted to enter a value in the event box. Enter the magnitude of the mass attached to the string, in grams.

Step 8: Repeat the data collection four more times, adding 100 g to the mass on the end of the string during each trial. Once the data have been collected, stop the data collection, close the data display box, and disconnect the EasyLink from the handheld (or Go! Link from the computer).

Step 9: Next, move to page 1.4, which contains a *Lists & Spreadsheet* application. You will use this application to calculate the resistance force.

Q3. How would you calculate the resistance force for each trial?

Step 10: Set column A equal to **dc01.event**, the data set containing the mass you recorded. Then set column B equal to **dc01.force1**, the data set containing the effort force data you collected. Label column A *mass* and column B *e_force*.

Step 11: Label column C *r_force*. Enter the formula for resistance force in column C and press ⏎. Column C should now display the resistance force for each trial. Study the data and then answer questions 4 and 5.

Q4. Compare the effort and resistance force for each mass.

Q5. What is the mechanical advantage of this pulley system?

Step 12: Next, you will use a graph to confirm your observations of mechanical advantage. Move to page 1.5, which contains an empty *Data & Statistics* application. Use this application to make a graph of *r_force* vs. *e_force*.
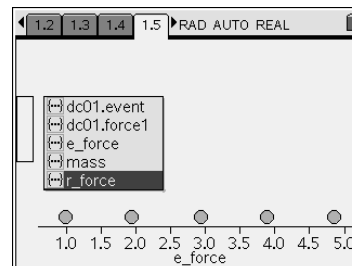
Step 13: Use the **Regression** tool to find the best-fit line for your data. Then, answer questions 6–8.
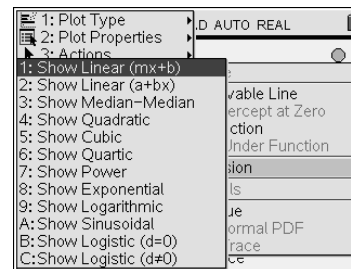
Q6. Does this graph agree with your answer to question 5? Explain your answer.

Q7. What is the advantage of using a single fixed pulley to lift a load?

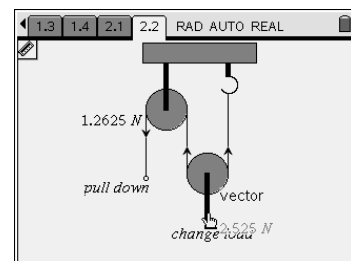**Q8.** Can you think of a way to use a single pulley to produce a mechanical advantage greater than 1?

Problem 2 – Pulley system simulations

Step 1: Next, move to page 2.1, which shows a simulation of a single-movable-pulley system. Use the **Length Measurement** tool to measure the lengths of the resistance force and the effort force. You can change the effort force by dragging point *pull up* up or down; you can change the resistance force by dragging point *change load* up or down.
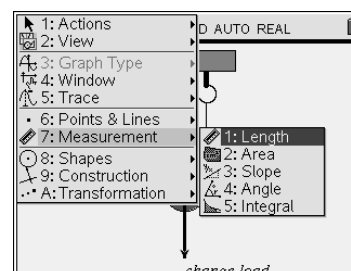
Q9. What is the mechanical advantage of this system? Explain your answer.

Q10. Do you think a single movable pulley would be easier or harder to use than the single-fixed-pulley system?

Step 2: Next, move to page 2.2, which shows a simulation of a two-pulley system. Again, use the **Length Measurement** tool to measure the lengths of the resistance and effort forces. Change the resistance and effort forces, and then answer question 11.

Q11. What is the mechanical advantage of this system? Explain your answer.