

## Math of Mechanical Advantage - Pulleys

### Objectives

Students will:

- Learn about pulleys and pulley systems.
- Learn how using multiple pulleys can dramatically reduce the required amount of work.
- Learn how pulley systems are used in machines and impact everyday life.
- Explain a 2:1 pulley system and understand that that ratio denotes the velocity (or) movement ratio.
- Learn about teamwork and problem solving in groups.

### Suggested Grade Levels:

3<sup>rd</sup> – 8<sup>th</sup> grades

### Subject Areas

Science, Technology, Engineering, Mathematics

### Timeline

50 – 60 minutes

### Standards

NGSS Standards

- **3-PS2-1.** Plan and conduct an investigation to provide evidence of the effects of balanced and unbalanced forces on the motion of an object.
- **3-5-ETS1-1.** Define a simple design problem reflecting a need or a want that includes specific criteria for success and constraints on materials, time, or cost.
- **3-5-ETS1-2.** Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
- **3-5-ETS1-3.** Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.
- **MS-PS2-2.** Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.
- **MS-ETS1-1.** Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
- **MS-ETS1-2.** Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

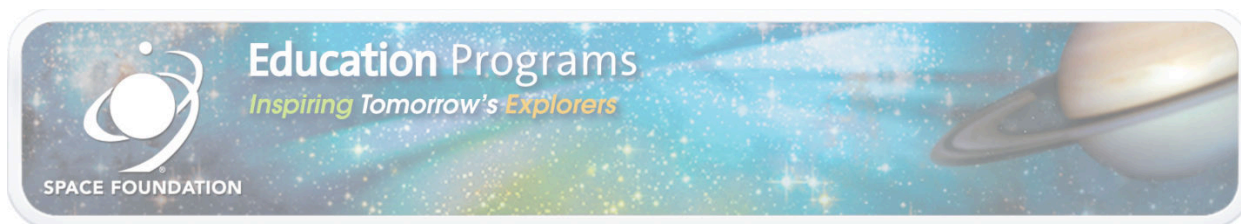
### 21<sup>st</sup> Century Essential Skills

- **Learning Skills**

- Critical Thinking, Analysis, Creativity, Collaboration, Communication

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- Literacy Skills
  - Information, Media, Technology, Environmental
- Life Skills
  - Flexibility, Leadership, Initiative, Productivity, Social, Public Speaking, Global Awareness, Listening

### **Background**

The Space Shuttle, the most complex machine ever built, weighs almost four and one-half million pounds. How does NASA lift the parts of the shuttle to join them together, and then move the entire assembly onto the launch pad? What if I told you that this can be done with technology that goes back thousands of years?!?!?

The wheel pulley was invented around 300 B.C., and has been in use ever since, impacting the way humans live, work, and play. Simple machines are devices with few or no moving parts that are used to modify motion and force in order to perform work, including: the inclined plane, lever, wedge, wheel and axle, pulley, and screw. This activity will discuss and demonstrate a pulley system, as well as cover forces, ratios, and mechanical advantage. In addition, students will discover that complex machines are 'simple' combinations of simple machines.

By placing a strongly anchored pulley above an object being lifted, humans can lift heavy objects much easier. By attaching another pulley to that same load, and then feeding the cord through a redirect pulley above, mechanical advantage has been applied. By doing this, the pulley system has effectively cut the load being lifted in half in terms of how much force is required to lift the load.

This lesson is the perfect way to introduce simple machines to students, learning how more math equates less work, all thanks to mechanical advantage, along the way!

### **Vocabulary**

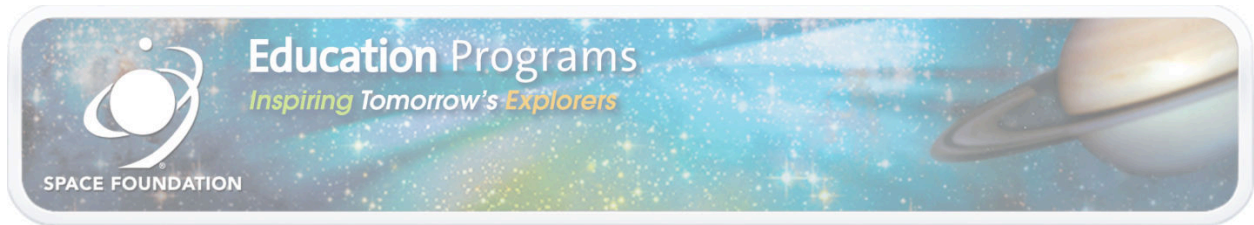
Cord, Force, Mechanical advantage, Simple Machine, Pulley, Ratio, Redirect, Velocity (or) Movement Ratio

### **Materials**

- Pulleys – 1 set per class
- Cords – 15 to 20 strands per class (3 ½ to 4 meters worth PLUS an extra strand of cord for the redirect line. It is important to have excess cord available for students to create connection loops as necessary.)
- C-Clamps – 1 set per class
- Carabiners – 1 set per class
- Tape measure – 1 per group
- Stacks of books – 1 stack per group

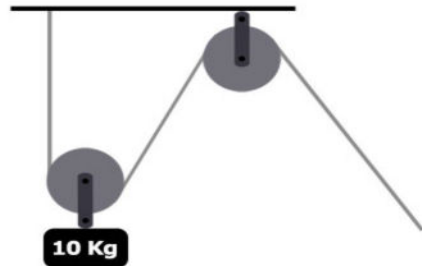
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## Lesson

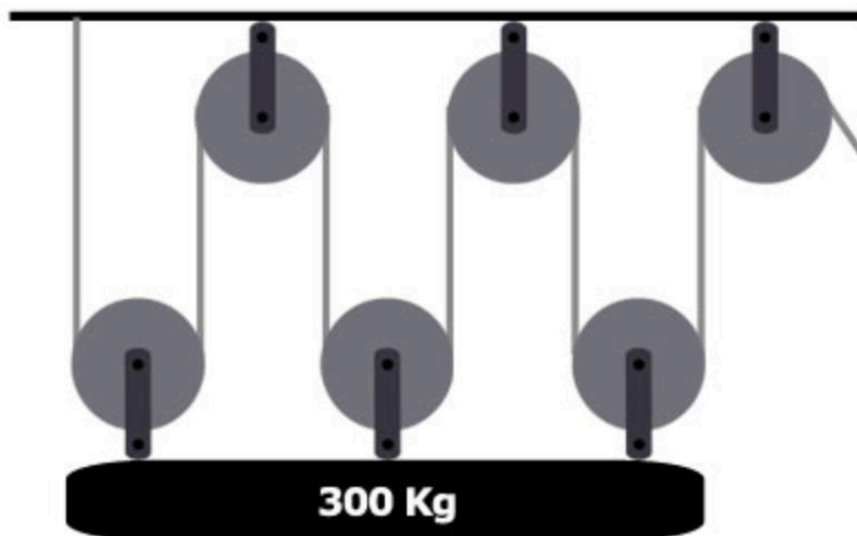
1. Ask students, "Once a rocket is assembled, how do you think engineers lift that rocket from a horizontal position to an upright, vertical position?"
2. Show students the following video, located on the next slide:
  - **"Crew Dragon & Falcon 9 Rolled Out to Launch Pad 39A" on the next slide.**  
<https://youtu.be/vsoqTfvGvEA>
3. Ask students, "What are pulleys?"
4. "Watch for examples of engineers using pulleys to make work easier as you watch the following videos."
  - Show students the following two videos, located on the next two slides:
    - **"360 View of SLS Core Stage Pathfinder Lift"**  
<https://youtu.be/lxGlxbSXR0>
    - **"360 View of SLS Core Stage Pathfinder Lift: Camera 2"**  
<https://youtu.be/zS77Mi1wVP4>
5. Divide students into groups of 2 or 3.
6. Tell the students that they will be building their own pulley system.
7. Pass out supplies to each group.
8. Imagine this stack of books is your 'shuttle.' I know you can lift these books with ease, but imagine these books weigh 165,000 pounds (The actual weight of an empty space shuttle).
9. Your goal is to lift your 'shuttle.' Allow 5-10 minutes for students to explore how pulleys work.
  - Attach a pulley to the load (the stack of books) and run the cord through the pulley.
  - Show students how to lift the load from above and have students visualize the load distribution, which illustrates the concept of mechanical advantage. This is a 1:1 ratio.
10. Display an image of a complete 2:1 pulley system with a redirect. Explain the role gravity plays in this process.
  - <https://www.spaceupclose.com/2019/10/sls-core-stage-pathfinder-goes-vertical-in-vab-at-ksc-photos/>
11. Explain to students that they will now transform their original 1:1 pulley system into a 2:1 pulley system by adding a redirect.
  - Attach a second pulley to the line.
  - Guide students through the process of attaching one end of the line to a high point in your classroom.
  - Place a second pulley on the rope that is attached to a highpoint. (This is the same rope that is attached to your first pulley.)
  - Explain that by simply adding this pulley, we are redirecting the direction of pull. This allows for an easier biomechanical purpose, using both body weight AND gravity to assist in reducing the effort.

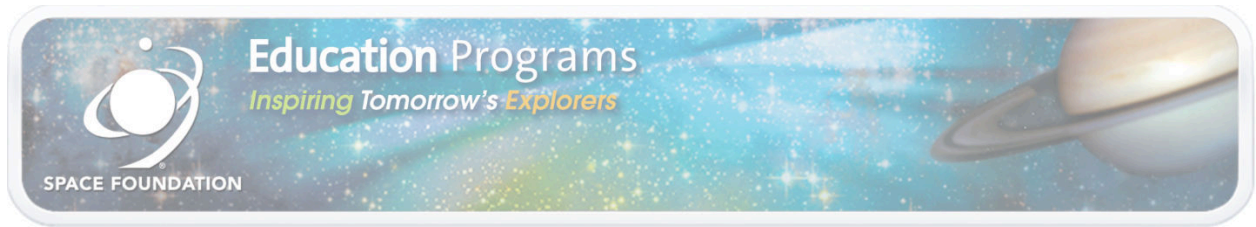


12. Tell students that they are now going to confirm the ratio by devising (on their own) a way to measure this 2:1 ratio. Explain that the string is measured out to be one full meter long.
13. Discuss successes and failures.
14. Students calculations should be as follows:
  - There should be two sections of rope extending off of the pulley that is attached to the load. Take the weight of the load (10Kg) and divide it by 2.  $10/2 = 5\text{Kg}$ . Student is lifting half the weight.

**Extensions:**

- Research other ways pulleys are used. Write an essay on how pulleys can be used on space missions.
- Explore using a 4:1 and 6:1 ratios. How are those different from a 2:1?
- Calculate the force needed to lift a 300kg weight using a 6:1 with a redirect.





Visit Space Foundation's website for more STEAM lessons and activities:

<https://www.discoverospace.org/>

### **Resources**

360 View of SLS Core Stage Pathfinder Lift - YouTube. (n.d.). Retrieved from <https://www.youtube.com/watch?v=lxGlxbSXR0>

360 View of SLS Core Stage Pathfinder Lift - YouTube. (n.d.). Retrieved from <https://www.youtube.com/watch?v=lxGlxbSXR0>

Crew Dragon & Falcon 9 Rolled Out to Launch Pad 39A - YouTube. (n.d.). Retrieved from <https://www.youtube.com/watch?v=vsogTfvGvEA>

Kremer, K. (2019, October 23). SLS Core Stage Pathfinder Goes Vertical in VAB at KSC: Photos. Retrieved from <https://www.spaceupclose.com/2019/10/sls-core-stage-pathfinder-goes-vertical-in-vab-at-ksc-photos/>

(n.d.). Retrieved October 25, 2019, from <http://www.compassproject.net/sims/pulley.html>

The Editors of Encyclopaedia Britannica. (n.d.).