

WHEEL AND AXLE

GEARS

PULLEYS

Materials:

- Pencil Sharpener diagram BLM 4.1
- Wheels as levers BLM 4.2
- Canada In Crisis Challenge BLM 4.7
- Gear Ratios (3 pages) BLM 4.9
- Pulleys diagrams BLM 4.11a
- Pulleys - questions (2 pages) BLM 4.11b
- Gears - the bicycle BLM 4.10
- Support Template BLM 4.3
- Pencil Profile BLM 4.4
- Mechanical Advantage of a Wheel and Axle
- Mechanism BLM 4.6
- Hand Winch Evaluation BLM 4.8
- cardboard
- pencils
- glue sticks for glue guns
- paper
- pins/tacks
- Plasticine
- string
- tape
- felt tip pens
- masking tape
- cord
- scissors
- hot glue guns
- fan
- pencil sharpener
- various sizes of plain wheel gears
- axles to fit gears
- base plates
- various bicycles with different gears
- single sheave pulleys
- double sheave pulleys
- variety of Newton spring scales
- assortment of textbooks
- lever boards with hooks
- chairs

Overall Expectation(s): 3. Demonstrate an understanding of different types of systems and the factors that contribute to their safe and efficient operation. (8s20); 2. Investigate a working system and the ways in which components of the system contribute to its desired function (8s19).

Structures and Mechanisms – Systems in Action – Wheel and Axle -

Description: This subtask involves several components related to wheels & axles. WHEELS & AXLES - This activity will allow the students the opportunity to build a hand winch using a wheel and axle. The students will be challenged to determine one or more practical applications for the devices they constructed based on the efficiency of each machine, and to discuss possible modifications to the wheel and axle mechanisms to better suit their needs.

Activity 1 - The Wheel and Axle

1. Clamp a pencil sharpener to the edge of a desk. Make sure the cover has been removed to expose the gears (BLM 4.1).
2. Turn the handle/crank of the sharpener clearly pointing out that the handle moves in a full circle forming the wheel. Point out to the students that the main shaft of the sharpener is the axle.
3. Tie two books together with a good solid string. Be sure to have plenty of free string for lifting the books.
4. Have several volunteers pick up the bound books by the string using one hand. Discuss what they felt in terms of the force needed to lift the books.
5. Now tie the loose end of the string to the shaft of the pencil sharpener (the axle). Make sure the string is attached firmly to prevent any slipping. Note: The axle in a wheel and axle mechanism is actually a wheel.
6. Slowly turn the crank raising the books. When doing so, use your finger to guide the string onto the shaft (the axle).
7. Note how much effort is necessary to raise the books.
8. Challenge the students to hypothesize: What work expenditure is required to raise the books easily? (Depending on the group you may have to lead/guide them.)
9. Calculate the mechanical advantage of your machine using the following formula:
 - o $MA = \text{Output} / \text{Input} = \text{radius of the axle} / \text{radius of the wheel (length of the crank)}$
 - o Note: When making a mathematical comparison, both units of measurement MUST be the same. For example if the radius of the axle is in centimetres then the radius of the wheel must be in centimetres as well.
10. Again raise the books by turning the crank.
11. Carefully let go (under control, you can well imagine what will occur if you just let go) of the crank.
12. Point out to the group that by letting go of the books, the axle is now turning the wheel.
13. Students should have made the observation that the books fall at a much faster speed compared to that at which they were raised. They should have also made the observation that the handle spins very rapidly compared to the slow pace at which you had to turn it in order to raise the books. Ensure that students also understand the difference between SPEED and VELOCITY. Define speed as a specific distance traveled within a specific time period (e.g., ten kilometres in five minutes). Define velocity as a speed in a specific given direction. Have students write this definition in their notebooks.
14. Give the picture of the pencil sharpener crank to the students and have them draw their own crank. They should use a compass to illustrate the wheel and axle. Label the following parts: Resistance (load), Effort, and the Fulcrum. (See blackline master BLM 4.2) Upon completion of their diagram, have the students identify the class of lever.

Activity 2 - Making A Hand Winch

1. Cut out a 15 cm x 15 cm piece of cardboard. This will be the base, so it should be fairly substantial.
2. Cut out the two supports using the same thickness of cardboard. (See BLM 4.3).
3. Make a small hole through the support near the top, with a diameter large enough to allow the pencil to spin freely.
4. Attach the two supports approximately 7 cm apart (this will depend on the length of the pencil) with a glue gun. The supports will need to be placed close to one end of the base. This will allow for variance in hand winch design. (See BLM 4.4).
5. Cut out a cardboard wheel with a diameter of 16 cm and punch a hole through its center to match the circumference of the pencil. The pencil should fit snugly into this hole.
6. Attach a handle to the wheel. Ensure that the handle is well fastened.
7. Push the pencil through the hole in the wheel so that the wheel is near the end of the pencil.
8. Place the pencil with the wheel attached into the support. You may have to place a small portion of plasticine on the pencil outside the supports to stop the pencil from sliding. Attach a 30 cm string with a mass on its end to the pencil (opposite end to where the wheel is).
9. Turn the wheel by the handle and observe what happens. The axle should turn at the same time as the wheel and the string should be wound around the pencil. The device will need to be fixed if this is not happening.
10. Set the wheel and axle mechanism back to its original position (sitting on the stand with the string completely unwound). Test the wheel and axle mechanism. Turn the handle and wind the string around the pencil. Stop when the string is completely wound around the pencil. Count how many turns of the wheel it takes to raise the mass. Record your observations on BLM 4.6 and calculate the Mechanical Advantage for this device.
 - $\text{Mechanical Advantage (MA)} = \text{diameter of the load wheel}$
 - $(\text{Output}) \text{ divided by diameter of the effort wheel (Input)}$.
 - Note: The axle in a wheel and axle mechanism is actually a wheel. This means that the axle can act as either the input wheel or the output wheel.
11. Repeat steps 5 to 10 using 12 cm, 8 cm, and 4 cm wheels.

Structures and Mechanisms – Systems in Action

– Gears -

Description: This subtask involves several components related to wheels & axles.

GEARS

There are two activities related to gear ratios. It is up to the teacher's discretion which activity they would like to incorporate depending on time and availability of equipment. In the first activity, students will work in small groups. They will use pairs of small gears which they will place on a base plate. They will rotate one of the gears and determine how many times the other turns compared with the first. From that, they will learn to predict gear ratios. In the second activity, either as a whole class or in small groups if enough bicycles are available, students will count teeth on bicycle gears and record the information on a chart they create. From this, they will calculate gear ratios and look at the effects of gearing up or down.

Activity 3 - Gears (choose one of the following 2 activities)

Activity #3A (Students may work in small groups or pairs.)

A student worksheet included as a blackline master (BLM 4.9 (3 pages)) gives a detailed method for this activity and provides discussion questions. If sufficient material is available, each group or pair will be given six gear wheels of different sizes. They are to count the number of teeth in each and measure the diameter of each. Then they are to take two gears of different sizes and attach them with axles to the base plate so that the teeth mesh. They then mark the point at which the two gears meet with a felt tip marker on each of the wheels. Select one gear and turn it one complete rotation. Determine how many times the other gear (the follower) turns. Record this information (1 ¼ turns, 2 ½ turns, etc.). Lastly they do calculations to determine the Mechanical Advantage for each pair of gears.

Mechanical Advantage (MA) = diameter of the load gear (follower) divided by diameter of the effort gear (driver)

Note: When calculating the Mechanical Advantage of wheel and axle mechanisms we are essentially comparing output to input (MA = Output / Input). To make this comparison one can measure the radius, the diameter, the circumference, or with gears the number of teeth. This comparison of output to input is also known as Velocity Ratio (VR). The calculation of Mechanical Advantage in this manner is however, more accurately referred to as the theoretical Mechanical Advantage since we are ignoring the effects of friction.

Discussion questions:

1. If the large gear is the driving gear, will the small gear turn faster or slower than the driving gear? Explain why.

A: The smaller gear will turn faster. Because it has fewer teeth, it will complete more rotations than the driving gear.

2. Is there a mathematical relationship between the gears when they are compared by diameter and by the the number of teeth?

A: The ratio of the two diameters will be equal to the ratio obtained by comparing the number of teeth on the two gears.

3. Can you predict how often the following gears will turn?

large gear - 80 teeth

small gear - 20 teeth

A: 1 turn of large gear- 4 turns of small gear

1 turn of small gear- 1/4 turn(s) of large gear

4 turns of small gear- 1 turns of large gear

4 turns of large gear- 16 turns of small gear

Activity #3B: Bicycle Gear Systems

1. Variable speed bicycles (ten speed, eighteen speed, twenty-one speed, etc.) are required for this activity. Provide students with a copy of Gears on a Bicycle - BLM 4.0 and discuss the purpose and use of the table. Teachers may wish to initiate this as a whole class activity to familiarize students with the process. The whole Class will select a bicycle to examine. Count the number of front gears and dn back gears. Check the table to ensure the correct number of gears are identified. Count the number of teeth on the largest front gear and the largest rear gear and record this information in an over head transparency of BLM 4.0 (For both front and back gears identify the largest gear as #1.) Calculate the velocity ratio and record this information on the overhead. Repeat this for another gear if you think students require more practice.

2. Individual or Group Activities - a number of bicycles are required. Have students select a bicycle to examine. They should:

-count the number of front and back gears, then design a table which will allow them to record the information for the appropriate number of gears.

- instruct them to examine this bicycle and to record the information on their tables

- calculate the velocity ratio of each gear

Discussion Questions:

1. What gear do you use for going uphill? Why?

2. Why do you need to pedal faster when you are in a lower gear?

3. What gears would you use to maximize your speed on level ground? Why?

4. If you try to stay in a higher gear when going uphill, what happens?

5. Explain what you think high gear and low gear means.
6. Why is the back gear considered to be the follower gear? Which gear turns the wheels?

Answers:

1. You use the lowest gears, e.g., one and two. You have to pedal a lot to move a short distance. Although less distance is covered, you are able to produce the force needed to overcome the extra pull of gravity on the incline. Remember that $Work = Force \times Distance$. Therefore, force is increased while distance is decreased.
2. In low gear, the smaller front gear is turning the largest back gear. The small gear has to complete more rotations for one rotation of the large gear.
3. On level ground, you can use a high gear. Not as much force is needed because it is easy to pedal on level ground. Therefore, you can increase your distance and consequently speed.
4. Your legs will ache because you can't generate the force or muscle power to turn at that gear ratio.
5. Low gear is when the smallest front gear drives the largest back gear. A small gear driving a large gear means that force is increased. High gear is when the largest front gear drives the smallest back gear. Distance is increased and therefore speed.
6. The back gears turn the rear wheels because the gears are attached to the axle of that wheel. The force from the pedals is applied to the front gear which is the drive gear. The front gear is attached to the axle driven by the pedals, not to the front wheel. The front gears are connect to the rear gears by the chain. As a result the force applied to the pedals is transferred from the front gears to the back gears.

Structures and Mechanisms – Systems in Action

– Pulleys –

Description: This subtask involves several components related to wheels & axles.

PULLEYS - Students will work in small groups to measure the Mechanical Advantage of pulleys. They will test a single fixed pulley system, a moveable pulley system, and compound pulley systems. They will measure the force required to lift a set load with each of the pulley arrangements. This will help them see that by increasing the number of ropes that support the load, the Mechanical Advantage increases and the load is easier to lift.

Activity 4 - Pulley Systems

Students will be working with two single sheave and two double sheave pulleys to measure the Mechanical Advantage obtained when you increase the number of ropes that support a load within a pulley system.

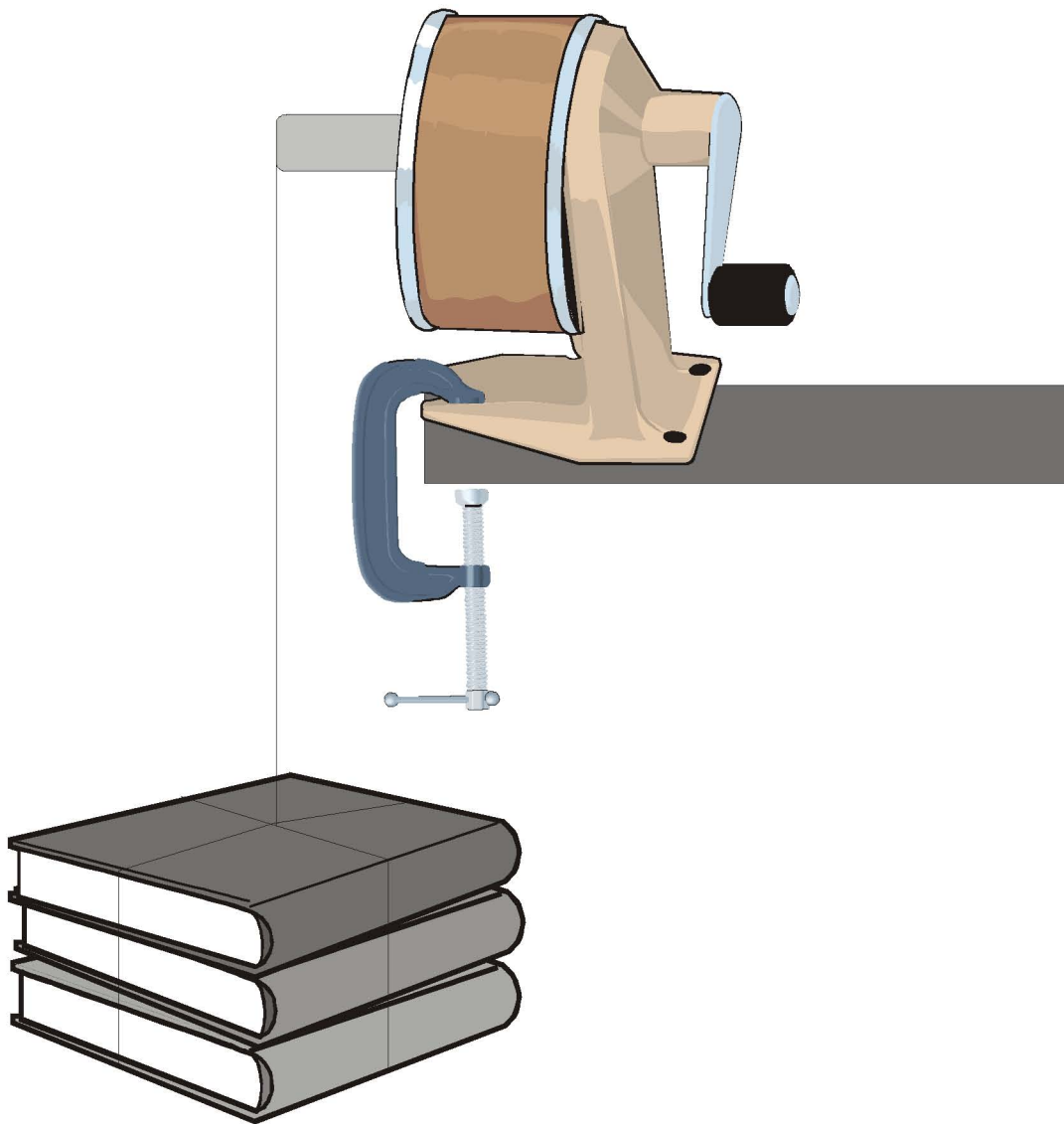
Note: A handout for the students is included which has several diagrams to clarify instructions. See BLM 4.11a for diagrams & BLM 4.11b (2 pages) for student activity sheet with outline of activity and provide follow-up questions.

1. Students will run the cord through one of the single sheave pulleys. The pulley will be suspended from a hook on the lever board that is placed upside down between two chairs. This is a single fixed pulley system. Using a Newton spring scale, they will measure the force needed to lift a load using the pulley and to lift the same load manually. The Newton spring scale will be tied to the end of the cord and students will take a reading while pulling evenly on the cord. They will observe that the single fixed pulley does not increase the mechanical advantage by reducing force. However, they should notice that it is easier to lift the load because they are pulling down rather than lifting up which allows them to use their body weight to help lift the load.
2. Students will attach the cord to the hook on the lever board, in place of the pulley. They will then run this cord through a single sheave pulley so that it is suspended from the cord. The weight (load) will be attached to the hook on the pulley. This is a single moveable pulley system. Students will attach a Newton spring scale to the load and pull on the scale to lift the load. Note the force needed to lift the load is now about half of that required to lift it manually.

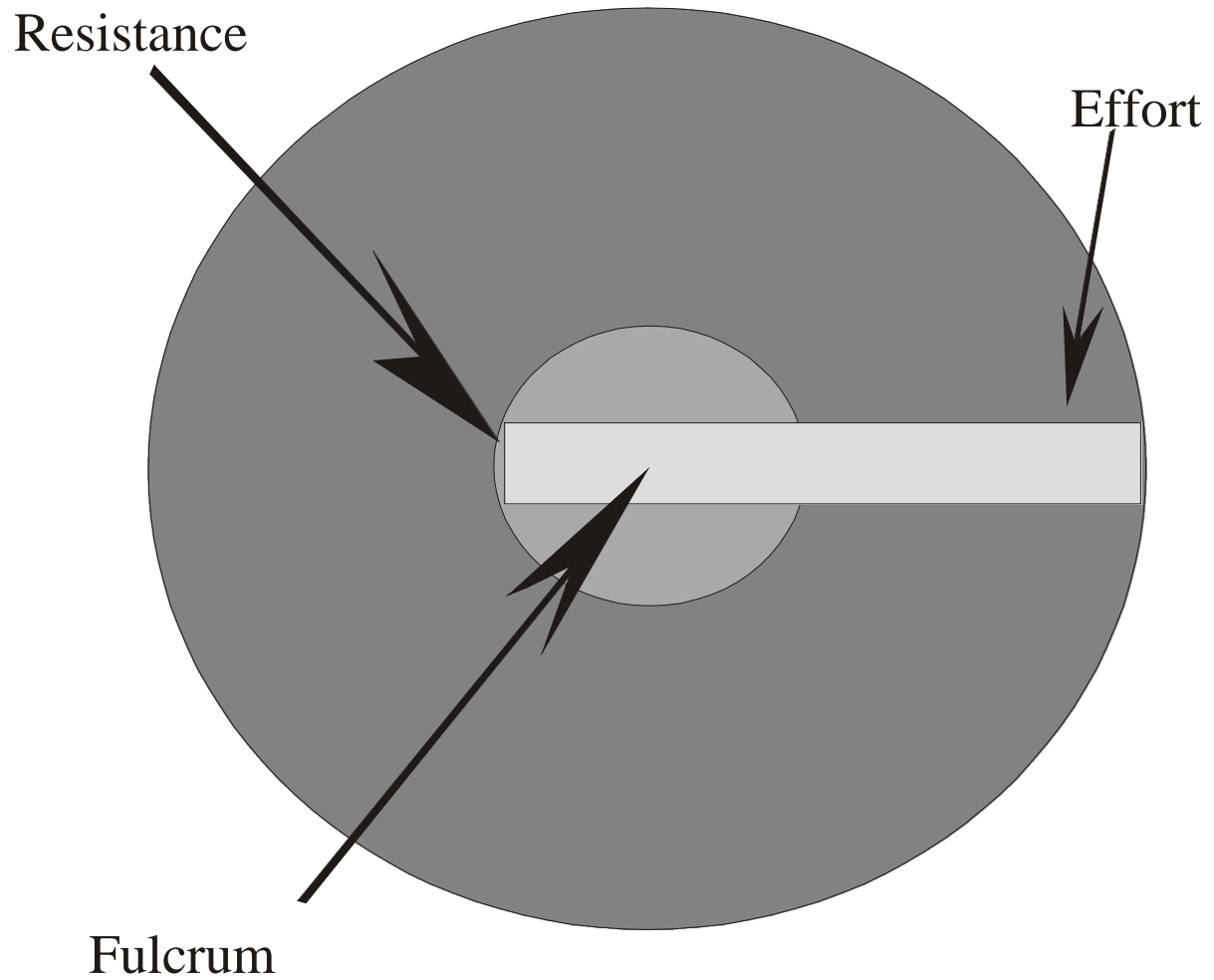
They then calculate the mechanical advantage.

3. Students will then reattach the single sheave pulley to a hook on the lever and attach the cord to the hook on the bottom of the pulley. The cord is then run through a second single sheave pulley which hangs below the first pulley and then up through the top pulley. Attach a Newton spring scale to the end of the cord. The load (textbooks) is suspended from the hook on the bottom pulley. This is a compound pulley system. Students pull on the Newton spring scale and note the amount of force required to lift the load. Note the force needed to lift the load is now about half of that required to lift it manually. They then calculate the mechanical advantage.
4. Students will replace the two single sheave pulleys with two double sheave pulleys in the same arrangement and as in #3 above run the cord through both sheaves of the pulley. This is a type of compound pulley system commonly referred to as a block and tackle. They will note the amount of force required to pull the load up. It should be about $\frac{1}{4}$ the force since four sections of rope now support the load, the mechanical advantage is four.

BLM 4.1

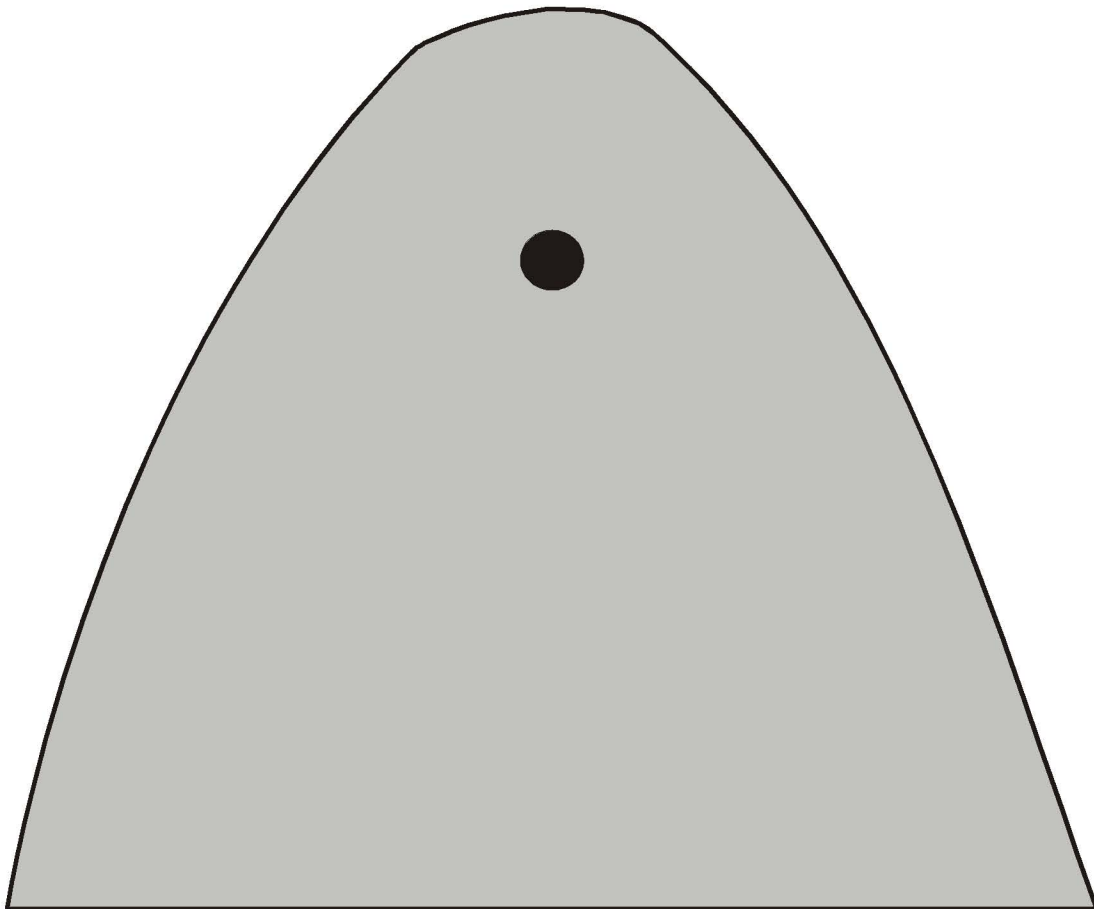


Wheels as Levers

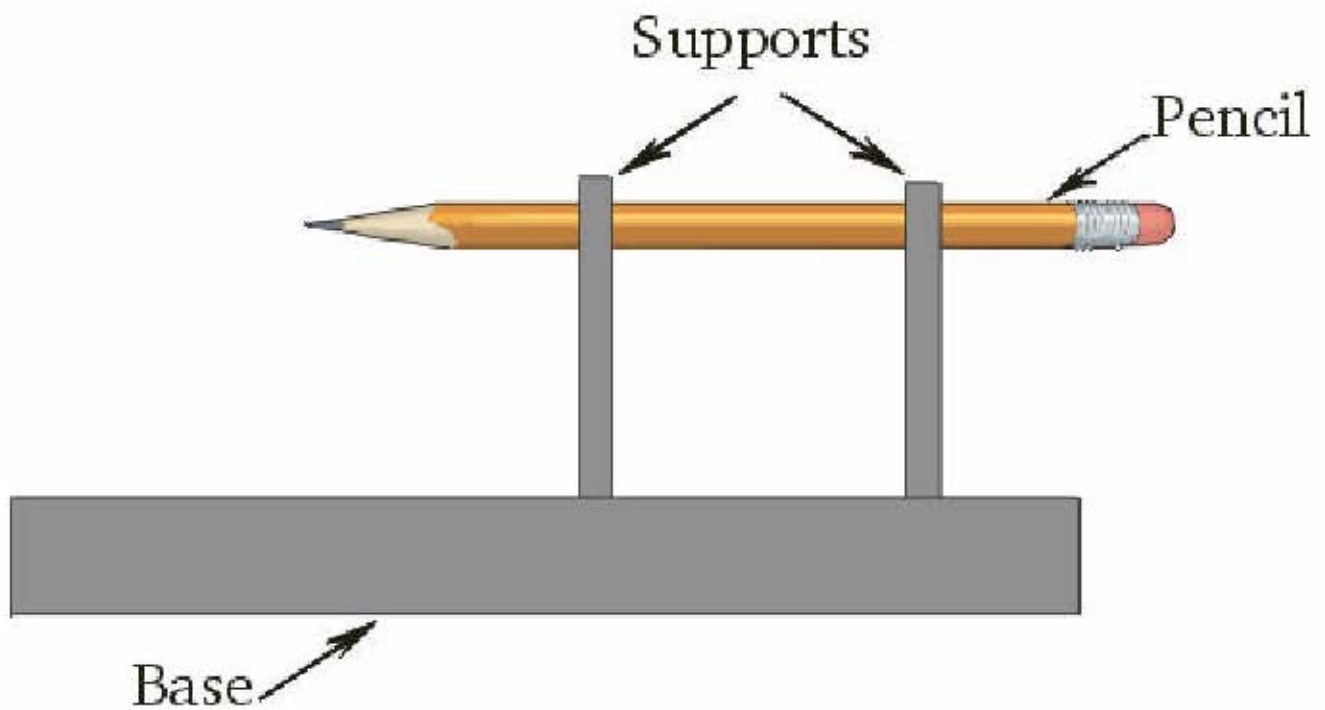


BLM 4.3

Support Template



Profile Diagram



Mechanical Advantage of a Wheel and Axle Mechanism

Wheel Diameter	Axle Diameter	Number of turns to raise the mass	Mechanical Advantage (MA)
16 cm			
12 cm			
8 cm			
4 cm			

$$\text{MA} = \text{Output} \div \text{Input} = \text{diameter of axle} \div \text{diameter of wheel}$$

TECHNOLOGY CHALLENGE

Name: _____

Date: _____

Situation: Canada In Crisis (Wheel & Axle Activity)

Canada is on the brink of disaster. Our nuclear reactors are old and extremely costly to replace. If something is not done quickly, we may run out of electricity. Think about that for a minute. Your environmental interests have always been focused on alternative power sources using the wind and water. As the world's leading scientist on mechanical advantage and efficiency, you have been asked to design and create a new power source for these renewable resources. You may choose to use them in combination or in isolation. You will need to produce a diagram illustrating your creation along with a brief description of your design proving its worth in terms of its mechanical advantage and efficiency.

Problem and Possibilities: _____

Ideas:

Design #1	Design #2

Equipment needed:	Equipment needed:
--------------------------	--------------------------

Design # _____ was chosen because _____

Choose / Construct: (step by step procedure)

Observations:

Evaluate:

Some of the challenges were: _____

Possible change(s) for next time would be _____ because

This device would be useful for _____

I am proud of my design because _____

BLM 4.8**RATING SCALE FOR EVALUATING HAND WINCH PROJECT**

Student Name: _____

Date: _____

		LEVEL			
A.	Demonstrates understanding of the project being investigated	1	2	3	4
B.	Follows directions carefully	1	2	3	4
C.	Uses appropriate equipment and materials	1	2	3	4
D.	Uses equipment/resources efficiently and accurately	1	2	3	4
E.	Observes all Safety precautions	1	2	3	4
F.	Identifies problems and solves them independently	1	2	3	4
G.	Identifies limitations and/or assumptions involved with their project	1	2	3	4
H.	Follows proper clean-up procedures	1	2	3	4

FURTHER COMMENTS:

BLM 4.9

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GEAR RATIOS**Materials List:**

- 6 different sized plain wheel gears from Spirogram™, Lasy Technical™, or Lego Technic™
- axles to fit gears
- base plate
- felt tip pen

Method:

1. Choose two gears of different diameters. Count the number of teeth on each gear. Measure the diameter of each gear to the nearest millimetre. Also record below.
2. Put each gear on an axle and insert the axle in the base plate so the teeth of the two gears mesh.
3. Mark on each gear with the felt tip pen the point at which they meet.
4. Manually turn the large gear (driver or driving gear). Count the number of times the small gear (driven gear or follower) turns.
5. Repeat these steps using two other pairs of gears.

Observations:*First pair of gears:*

	Diameter	Number of Teeth
small gear		
large gear		

Answer the following questions:

- I. 1 turn of the large gear: _____ turn(s) of the small gear.
- II. Calculate gear/velocity ratios (simplify each answer).

Diameter of large gear

Diameter of small gear

Number of teeth on large gear

Number of teeth on small gear

BLM 4.9*Second pair of gears:*

	Diameter	Number of Teeth
small gear		
large gear		

Answer the following questions:

- I. 1 turn of the large gear: _____ turn(s) of the small gear.
- II. Calculate gear/velocity ratios (simplify each answer).

Diameter of large gear
Diameter of small gear

Number of teeth on large gear
Number of teeth on small gear

Third pair of gears:

	Diameter	Number of Teeth
small gear		
large gear		

Answer the following questions:

- I. 1 turn of the large gear: _____ turn(s) of the small gear.
- II. Calculate gear/velocity ratios (simplify each answer).

Diameter of large gear
Diameter of small gear

Number of teeth on large gear
Number of teeth on small gear

BLM 4.9

Page 3 of 3

Discussion:

1. If the large gear is the driving gear, will the small gear turn faster or slower than the driving gear? Explain why.

2. Is there a mathematical relationship between the diameter ratio of gears and the ratio for the number of teeth on gears?

3. Can you predict how often the following gears will turn IF the large gear has 80 teeth and the small gear has 20 teeth?
 - 1 turn of large gear - _____ turn(s) of small gear
 - 1 turn of small gear - _____ turn(s) of large gear
 - 4 turns of large gear - _____ turn(s) of small gear
 - 4 turns of small gear - _____ turn(s) of large gear

Conclusion:

When you calculate how fast one gear turns relative to another, you are finding the *velocity ratio*. Write the formula one would have to use to calculate *velocity ratio* for any pair of gears.

In comparing the sizes of gears, you can find the *mechanical advantage* of one gear compared to another. Write a formula you could use for calculating *mechanical advantage* with gears.

Student handout BLM 4.10

GEARS ON A BICYCLE

Complete the following table for both front and back gears (call **gear 1** the one with the **most** teeth):

POSITION	GEAR #	# OF TEETH
FRONT	1	
	2	
	3	
BACK	1	
	2	
	3	
	4	
	5	
	6	
	7	

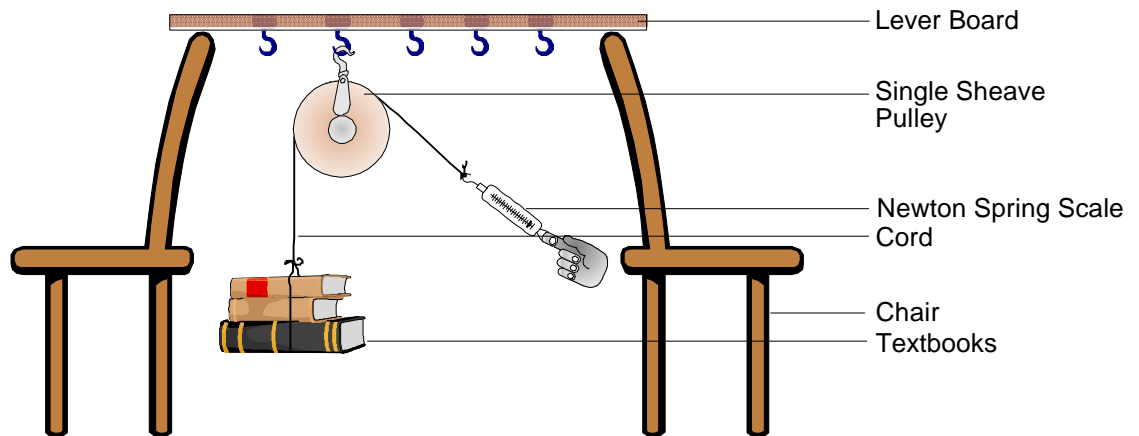
VELOCITY RATIO

Calculate velocity ratio in column 3 for each of the following gear combinations:

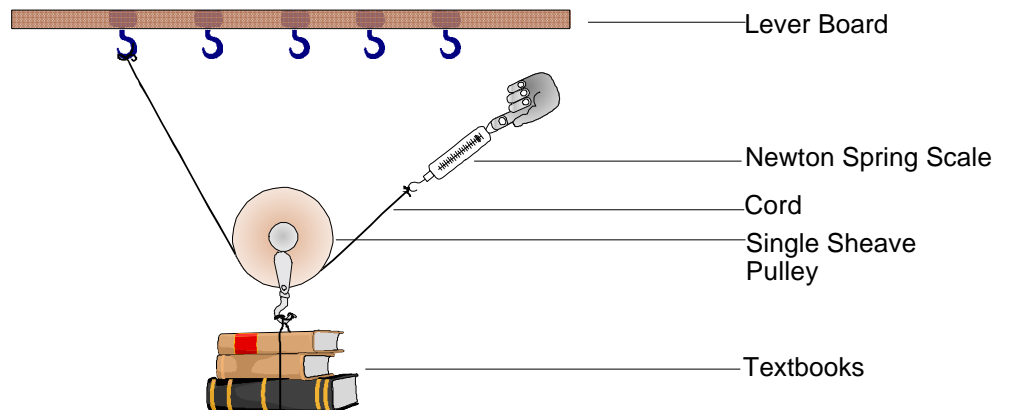
FRONT 1 with	BACK 1	_____
	BACK 2	_____
	BACK 3	_____
	BACK 4	_____
	BACK 5	_____
	BACK 6	_____
	BACK 7	_____
FRONT 2 with	BACK 1	_____
	BACK 2	_____
	BACK 3	_____
	BACK 4	_____
	BACK 5	_____
	BACK 6	_____
	BACK 7	_____
FRONT 3 with	BACK 1	_____
	BACK 2	_____
	BACK 3	_____
	BACK 4	_____
	BACK 5	_____
	BACK 6	_____
	BACK 7	_____

Pulley Activity - Student Handout (BLM 4.11a)

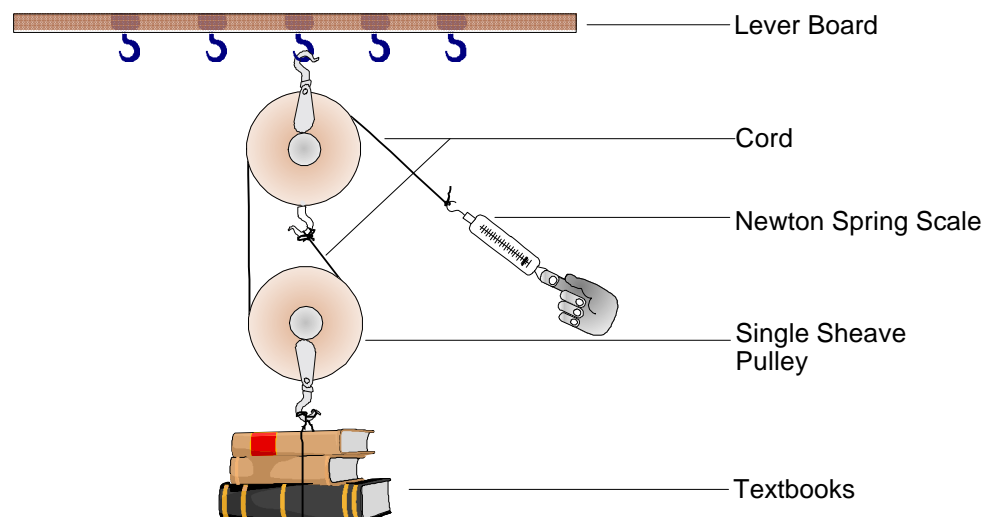
1. Single Fixed Pulley



2. Single Moveable Pulley



3. Compound Pulley



PULLEYS

MATERIALS LIST:

- 2 single sheave pulleys
- 2 double sheave pulleys
- variety of sizes of Newton spring scales
- 2 textbooks attached together with masking tape
- lever board with hooks
- 2 chairs
- cord

METHOD:

Single Fixed Pulley System

1. Zero-off the Newton spring scale. Attach two textbooks together using masking tape and a piece of cord to enable you to hang them from a hook. Weigh your load using the spring scale by hanging it from the hook on the spring scale. Record under Observations.
2. Support the lever board upside down between the backs of two chairs so that the hooks hang downwards. Attach one of the single sheave pulleys to the hook so that it hangs downward. Run the cord through the pulley.
3. Attach your load to one end of the cord.
4. Attach the Newton spring scale to the other end of the cord. Pull evenly on the Newton spring scale so that you raise your load. Note the force required to lift the load.

Single Moveable Pulley System

1. Detach the pulley from the hook and instead attach one end of the cord to the hook. Run the other end of the cord through a single sheave pulley so that the pulley is suspended from it.
2. Hang the textbooks on the hook on the bottom of the pulley.
3. Attach the Newton spring scale to the loose end of the cord. Pull the cord upwards by the Newton spring scale attached to it and note the reading. Record.

Compound Pulley System

1. Again hang a single sheave pulley from the hook and attach the end of the cord to its bottom hook to hang straight down.
2. Run the end of the cord through a second single sheave pulley which hangs below the first pulley.
3. Suspend the load from the hook on the bottom of the moveable (suspended) pulley.
4. Run the cord upwards and around the top pulley. Attach a Newton spring scale to the end and note the amount of force required now to lift the load. Record.
5. Repeat the above steps using two double sheave pulleys in the same arrangement.
6. Note the amount of force required to pull the load up when you pull on the Newton spring scale. Record.

OBSERVATIONS:**Single Fixed Pulley System**

1. Force to lift load manually - _____ N
2. Force to lift load using single fixed pulley - _____ N

Single Moveable Pulley System

1. Force to lift load manually - _____ N
2. Force to lift load using single moveable pulley - _____ N

Compound Pulley System (single sheave)

1. Force to lift load manually - _____ N
2. Force to lift load using single sheave compound pulley - _____ N

Compound Pulley System (double sheave)

1. Force to lift load manually - _____ N
2. Force to lift load using double sheave compound pulley - _____ N

CALCULATIONS:

MECHANICAL ADVANTAGE: $\frac{\text{weight of load}}{\text{effort force}}$ **OR** $\frac{\text{load force}}{\text{effort force}}$

Single Fixed Pulley System

Mechanical Advantage = (#1/#2) =

Single Moveable Pulley System

Mechanical Advantage = (#1/#2) =

Compound Pulley System (single sheave)

Mechanical Advantage = (#1/#2) =

Compound Pulley System (double sheave)

Mechanical Advantage = (#1/#2) =

DISCUSSION:

1. What is the main use of a single fixed pulley?
2. How does the *Mechanical Advantage* of the moveable pulley system compare with that of the single fixed pulley system?
3. Compare the *Mechanical Advantage* of the single sheave compound pulley system with that of the double sheave compound pulley system. Which is greater and why?
4. Predict what the *Mechanical Advantage* would be if you used two triple sheave pulleys.