

## Max Your Ride: Worksheet

This activity will take you through the steps needed to optimize the work used in your mousetrap car. Follow this worksheet in order.

Refer to previous activities' experimental measurements and calculations where possible. You may need to repeat this activity.

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Calculate the efficiency associated with one rotation of the axle

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We can calculate the efficiency of one rotation of the axle by examining the work done.

$F$
$F_s =$
$F_k =$

You measured the static frictional force,  $F_s$ , in "Dragged Racers." We can calculate the work done by the frictional force for one rotation if we know the length of the path that this force acts.

The path is related to the size of the wheel – it is the circumference. Compute the circumference – you measured the radius in "Quantify It":

$$C = 2\pi \cdot r = (2\pi) \cdot (\quad \text{m}) =$$

Compute the work done by the frictional force, $W_f$ :
$W_f = F_s \cdot C = (\quad \text{N})(\quad \text{m}) =$

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Calculate the Torque caused by a load:  $T = F \cdot d$

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In “Spinners,” we turned the axle by using a known force – a weight. When set into motion, the mousetrap provides the force that propels the car. You might have measured the force previously in “Quantify It” or “Convert It,” but do so now before continuing. Record the force below.

Mousetrap force,  $F_m =$  \_\_\_\_\_ N

We also need to know the distance that the force acts in order to calculate the torque resulting from the force. This distance is the radius of the axle.

Axle radius,  $r_{axle} =$  \_\_\_\_\_ m

Torque from mousetrap force:

$$T_m = F_m \cdot r_{axle} = ( \quad \text{N} ) ( \quad \text{m} ) =$$

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Calculate the Work done by Torque:  $W = T \cdot \theta$

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Now that we know the torque caused by the mousetrap force,  $T_m$ , the work can be calculated if we know the angle,  $\theta$ , that the torque acts through.

Since we are dealing with one rotation (or revolution), the angle is equal to  $360^\circ$ , or  $2\pi$  radians.

Torque from mousetrap force:

$$W_m = T_m \cdot \theta = ( \quad \text{N} \cdot \text{m} ) ( 2\pi \text{ rad} ) =$$

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Calculate the Efficiency of Mousetrap Car:  $E = \frac{\text{Work out}}{\text{Work in}}$

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Let's assume that the car only uses energy to overcome friction. Then we could reason:

(Work out) = (Friction Work); (Work in) = (Mousetrap Arm Work)

Since the work of the mousetrap is expended on static friction.

The efficiency of the mousetrap car is the ratio of the output to the input work.

$$\text{Efficiency} = \frac{\text{Work out}}{\text{Work in}} = \frac{\text{N} \cdot \text{m}}{\text{N} \cdot \text{m}} =$$

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### Improve the Efficiency

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If we know the external forces acting on the car (friction, normal force), we can optimize the length of parts on the car so that it does not waste energy.

Since we are only considering static friction as an external force, we should tune the car so that the force of the mousetrap equally opposes this force.

We have to find the acceleration of the wheel needed to act against the frictional force. What equation relates Force and Acceleration? Newton's 2<sup>nd</sup> law:  $F = m \cdot a$ .

Use the mass of the car (calculated in "Dragged Racers") and the frictional force to calculate the necessary acceleration for the wheel:

$$a = \frac{F_s}{m_{car}} = \frac{\text{N}}{\text{kg}} = \frac{\text{m}}{\text{s}^2}$$

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Relate linear acceleration to angular acceleration:  $\alpha = \frac{a}{r}$

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We had to do relate linear and angular acceleration in “Spinners”: we’re doing the same operation in this calculation.

$$\alpha = \frac{a_{car}}{r_{axle}} = \frac{\text{m/s}^2}{\text{m}} = \text{rad/s}^2$$

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Find the necessary Torque:  $T = I \cdot \alpha$

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In “Spinners,” we found the moment of inertia,  $I$ , of the rear axle based on how it accelerated in response to an applied torque.

Use the moment of inertia calculated in “Spinners” and the angular acceleration calculated above to determine the torque necessary to move the car without the wheels overcoming static friction and slipping as a result.

$$T_{axle} = I_{axle} \cdot \alpha_{wheel} = (\quad \text{kg} \cdot \text{m}^2)(\quad \text{rad/s}^2)$$
$$T_{axle} =$$

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Find the force needed to produce  $T_{axle}$ :  $T = F \cdot d$

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We’re trying to rotate the axle, and now that we know the torque needed to cause the desired rotation, we can find the force that must be transferred from the mousetrap.

$$F_{mousetrap} = \frac{T_{axle}}{r_{axle}} = \frac{\text{N} \cdot \text{m}}{\text{m}} = \text{N}$$

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## Scale the Force, Scale the Torque

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We can use the idea of mechanical advantage to lift the mousetrap arm – if we attach a rod to the arm, it takes less effort to oppose the spring force. How will the extended mousetrap arm apply force on the axle?

**Hint: Newton's 3<sup>rd</sup> Law: For every action there is an equal and opposite reaction**

According to Newton's 3<sup>rd</sup> law, extending the mousetrap arm will result in lower forces being applied to the drive axle.

This is a good thing if we have too much force transferred from the mousetrap spring to the axle: we can scale the force based on the distance away from the mousetrap base.

Use a proportion! If you know the force ( $F_{arm}$ ) measured at a certain point from the spring ( $d_{arm}$ ), you can find the distance,  $d_{extension}$ , that the mousetrap arm must be.

$$\frac{F_{arm}}{d_{arm}} = \frac{F_{mousetrap}}{d_{extension}}$$

$$d_{extension} = d_{arm} \left( \frac{F_{mousetrap}}{F_{arm}} \right) = ( \quad \text{m} ) \left( \frac{\quad \text{N}}{\quad \text{N}} \right)$$

$$d_{extension} = \quad \text{m}$$