

MONSTER TRUCKS

TEACHER'S
ACTIVITY
GUIDE
GRADES
9-12

SANCTIONED BY



UNIT 2

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CLEARCHANNEL
EXHIBITIONS

Introduction

Welcome to *Monster Trucks: The Science of Extreme Machines!* As an educator, you have the Monster task of turning your students on to learning. We hope that this guide, in combination with the Monster Trucks traveling exhibit, helps fuel your students with a drive to learn.

The big beasts that are Monster Trucks exemplify many concepts and principles that are core components of math, physics, and auto technology classes. As a result, this guide provides a focus on three different units, so you can choose the lessons that best meet your classroom needs:

- ☛ **Math and Science Lessons for Grades 4 – 8**
- ☛ **Physics Lessons for Grades 9 – 12**
- ☛ **Auto Technology Lessons for Grades 10 – 14**

All of the lessons in this guide have been designed to complement the amazing *Monster Trucks: The Science of Extreme Machines* traveling exhibit. The lessons are standalone, using inquiry-based and hands-on approaches that enable students to recognize real-world applications of some of the skills and knowledge that are important to your classroom goals. Additionally, many of the lessons include reproducibles for you to use as handouts or on the overhead.

Units

Math and Science Lesson Plans for Grades 4 – 8

Covering a wide scope of student ages and abilities, this unit offers multiple tracks for you to take. Each lesson offers explicit suggestions on how to make it more or less challenging to better meet your students' needs. The unit is divided into a mathematics track and a physics track — each consisting of three separate lessons.

The math lessons emphasize skills that relate directly to National Council of Teachers of Mathematics standards including: Numbers and Operations, Algebra, Measurement, and Data Measurement and Probability.

The science lessons tie into the Physical Science standard (Content Standard B) of the National Science Education Standards, specifically the standard's emphasis on Motions and Forces, and on Transfer of Energy. They also tie into Content Standard E on Science and Technology.

Physics Lesson Plans for Grades 9 – 12

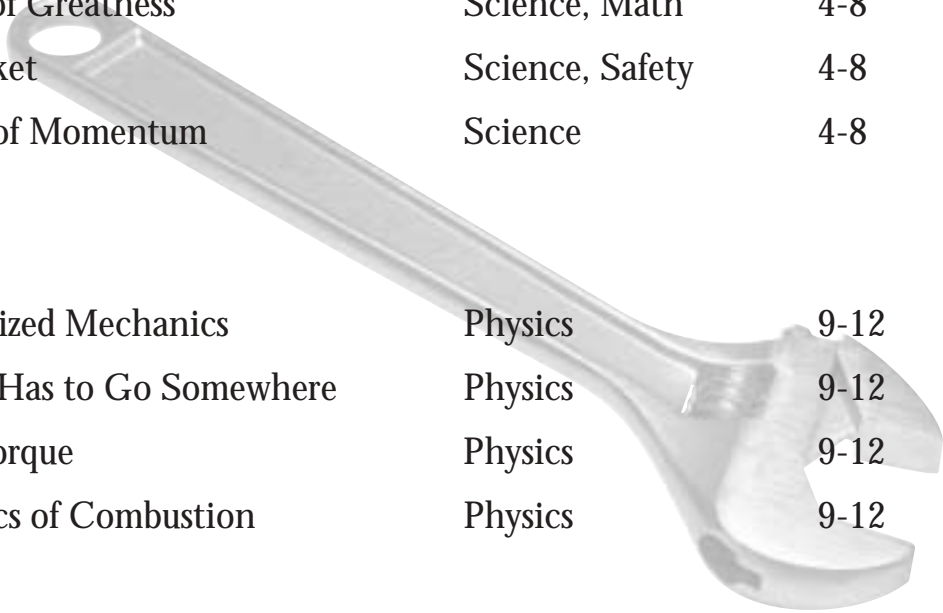
The lessons within this unit build off of many concepts that are important to a physics curriculum. In order to maximize the likelihood of having lessons that would tie into your specific curriculum at the time of the exhibit, the guide presents topics that are introduced at different times within a physics course. However, because the lessons are standalone, you can use them whenever they are most appropriate for your course of study. The lessons tie into the National Science Education Standards' Physical Science (Content Standard B), specifically to the standard's emphasis on chemical reactions, motions and forces, and conservation of energy.

Auto Technology Lesson Plans for Grades 10 – 12+

This unit takes advantage of the similarities and differences between the worlds of an auto shop and a Monster Truck shop. By better understanding those similarities and differences, students will increase their understanding of the two themes at the heart of this section: Engines and Safety. Each of the lessons cites the NATEF Standards for Certification that apply to it, and are appropriate for intro level auto technology classes through a post- high school level program.

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• MONSTER-SIZED MECHANICS

Objectives:

Students will learn to measure the acceleration of vehicles undergoing constant acceleration and will practice graphing the results. Students will then use the mass of the vehicle and its acceleration to compute the net force. Students will complete a force diagram for a Monster Truck and compute the motive force of a Monster Truck engine. Finally, given the angle of an incline (off of which a Monster Truck jumps) and the initial velocity, students will compute the height and length of the jump.

Curriculum Connection:

These activities provide an excellent way to introduce students to measurements of acceleration, graphical analysis of motion, Newton's Second Law of Motion, force diagrams, and the analysis of projectile motion. Although students may have covered this material in a lecture, hands-on activities make the abstract physics concrete.

Kinematics and dynamics are covered first in most physics curricula. Kinematics involves a description of motion (velocity, acceleration, etc.) while dynamics entails the causes of motion (forces). The combination of kinematics and dynamics is known as mechanics. This lesson uses paper and pencil as well as lab activities in order to provide students with a better understanding of the mechanics of motion.

Since Monster Trucks have an initial velocity of zero (and accelerate to some maximum velocity), students will measure different acceleration curves as a pre-activity in class. Although these labs explore constant acceleration curves, realistic vehicles, having a gas pedal and a transmission, exhibit non-linear acceleration curves. Several assumptions can be made, depending on the ability level of students. For a regular level class, students can assume a constant acceleration and compute it from the initial and final truck velocities. More advanced classes can contemplate a step function as drivers shift gears. AP/IB classes (which often take a calculus approach) can use “real” acceleration curves and compute derivatives.

Once students determine the acceleration, they can compute the net force acting on the Monster Truck using the formula ($F_{\text{net}}=ma$). Depending on which of the above assumptions is used, the corresponding net force can be derived (constant force, step function, or derivatives). Given knowledge of the coefficient of friction between the wheels and the road and the mass of the truck, the motive force of the engine can be computed after constructing a force diagram. It's awesome!

The final part of the lesson examines one of the more exciting things about Monster Trucks—when they “catch some air.” This is a study of projectile motion. Such motion is best analyzed by resolving the velocity into a vertical component (a function of gravity which varies) and a horizontal component (which is constant) gained from the Monster Truck while still on the ground. The distance it travels as well as the height it jumps are a function of the initial velocities before take-off and the angle of the ramp used. Students will set up ramps and use wind-up cars to simulate the effect.

Class Time:

Acceleration Pre-activity: one 50-minute class period to measure, 1/2 period to graph

Force Analysis: 50 minutes

Projectile Motion: 50 minutes

Important Terms: acceleration, coefficient of friction, net force, projectile motion

Exhibit Link:

This lesson can be completed either as a pre-or post-exhibit activity. The exhibit's computer simulation of driving a Monster Truck will give a sense of acceleration, deceleration, and what it's like to “catch some air.” This lesson helps students understand the physics behind these motions.

Materials Needed:

- ☞ carts
- ☞ protractors
- ☞ wind-up or battery-operated cars
- ☞ rulers
- ☞ graph paper
- ☞ ticker-tape timers (or stopwatches)
- ☞ incline planes (the longer the better; wide boards are good)

Lesson Steps:

This lesson contains three parts: measuring acceleration, completing a force analysis, and analyzing projectile motion.

Part 1: Measuring Acceleration

1. **Instruct students or student teams to place a cart on the top of an inclined plane (an angle between 20°-40° is best) and connect the ticker-tape timer to it.** After activating the timer, they should let the cart roll down the incline.
2. **After the cart stops, students should measure the distance between “ticks” on the ticker tape.** These measurements should then be organized in tabular format showing the cumulative distance between ticks and the time interval. The time interval to each tick equals the number of ticks (attained by counting ticks) times the length of time between a pair of ticks. That value is typically 1/60 of a second but may vary across timers.
3. **Using the graph paper, have students graph these cumulative distances against the time interval.** This graph will show positive acceleration (i.e., the graph will be non-linear with an increasing slope).
4. **Using their graphs, students should:**
 - estimate the slope of this graph at several points (the slope is an estimate of the speed at that point in time)
 - graph these speeds against the time at which each was taken.
5. **Using their graph of speed against time, students then compute the slope of the curve, which is the acceleration of the cart.**

Part 2: Force Analysis

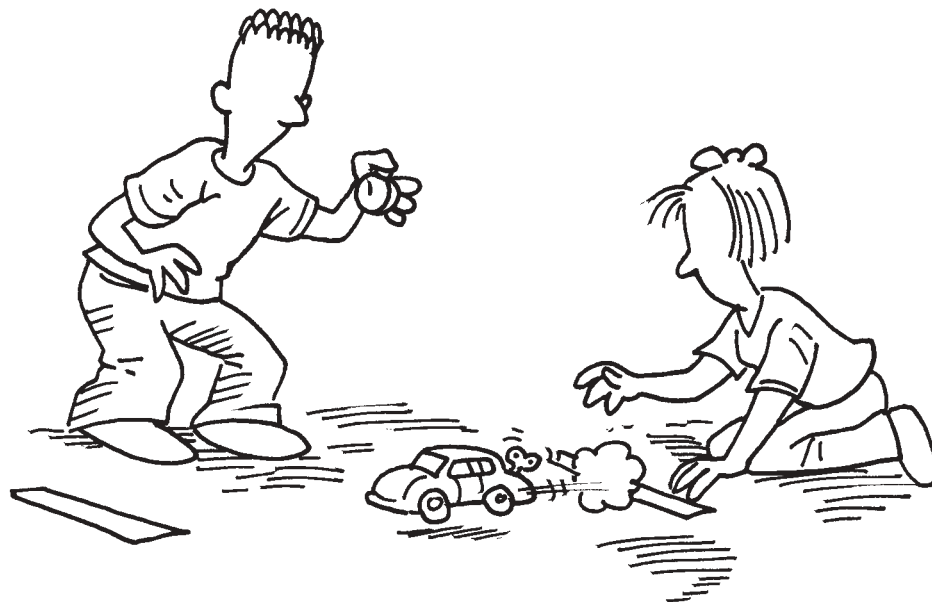
1. **Using the same materials as Part 1, students should measure the mass of the cart using a balance.**
2. **Then, using a protractor, students should measure the angle (α) of the incline set up in Part 1.**
3. **Given the mass and the acceleration (value derived in Part 1), instruct students to compute the following equations for force acting on the cart:**
 - a) net force ($F_{\text{net}} = m \cdot a$)
 - b) gravitational force ($F_g = m \cdot g$, where $g = 9.81 \text{ m/s}^2$)
 - c) normal force ($N = m \cdot g \cdot \cos \alpha$, where $\alpha =$ angle of the incline)
 - d) friction force ($f = u_k \cdot N$, where $u_k =$ the co-efficient of friction. A value of 1.0 is reasonable for this lesson.)
4. **Guide students in using vector addition to add the gravitational force, the normal force, and friction force.** The sum should equal the net force.
5. **Now, to compare these forces on a larger scale, supply students with the following data:**

Truck	Mass	Constant Speed
Blue Thunder	10,400 lbs	70 mph

Given the acceleration and mass of Blue Thunder traveling on a level surface ($\alpha = 0$), students should repeat Step 3 and record their calculations for forces acting on the trucks. (Students must first convert the lbs and mph to metric values.)

Note: Be sure to point out that since the truck is moving at a constant velocity, its acceleration is zero.

6. **Guide students in finding the sum of the gravitational, normal, and friction forces in Step 5 using vector addition.**
7. **Lead students to observe that the sum of those forces does not equal the net force calculated in Step 5.** Ask students why they think that is so. (Answer: The motive force supplied by a Monster Truck engine has not been accounted for yet.)
8. **Instruct students to create a Free Body Diagram of the Monster Truck.** If the net force and friction force are known, ask students how they can determine the f_{engine} . (The answer is explained in Step 9.)
9. **Guide students in using vector subtraction to find the difference between the net force and the other forces calculated in Step 5.**
10. **Ask students to observe that the difference in forces in Step 9 equals the motive force of a Monster Truck.**



Part 3: Analyzing Projectile Motion

In this section, students will use the initial velocity [v] of a Monster Truck and the angle [α] of the jump ramp (a typical value is 20°), to compute the horizontal [$v_x = v \cdot \cos\alpha$] and vertical [$v_y = v \cdot \sin\alpha$] components of velocity in a Monster Truck jump.

1. **Lead students to observe that the vertical component determines the height of the jump [$d_y = (v_y t) - (gt^2/2)$] as well as how long [$t = v_y/g$, $g = 9.81 \text{ m/s}^2$] the Truck is in the air.** Further, students will note that this time and the horizontal component can be used to compute the length [$d_x = v_x t$] of the jump.
2. **Students should use the velocity values they compute (v_x and v_y) and the equations from Step 1 to compute the height and length of a typical Monster Truck jump.**
3. **If time permits, these predictions can be tested by setting up ramps (at various angles), running cars up them, and measuring the height and distance of the jumps.** If the initial velocity and angle are known, the length of the jump can be predicted and compared with the measurements.

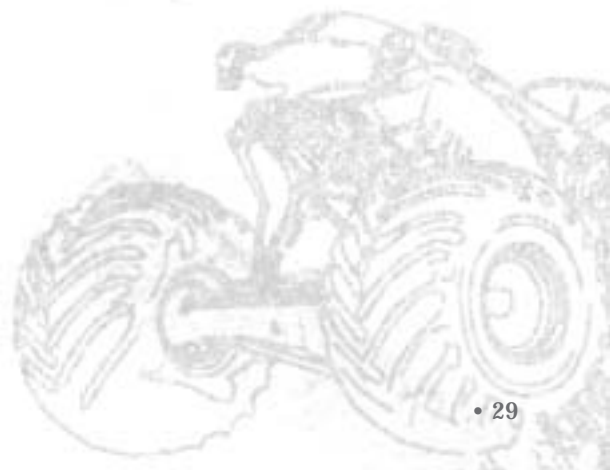
4. **Student teams can use the following steps to test these predictions.** This experiment works best with fast moving cars, short take off ramps, and small angles of incline:
- Map out a course and measure the distance from beginning to end.
 - Run the battery-operated car along this course and measure the time it takes to complete the course with a stopwatch. Compute the velocity using $\text{velocity} = \text{distance}/\text{time}$.
 - Set up a ramp and measure the angle of the incline.
 - Repeat **Steps 1 and 2** above but use the velocity of the car and the angle of the ramp to predict the length and height of a jump.
 - Direct the car to run up the ramp.
 - Note where the car lands after running off the ramp.
 - Measure the distance from the end of the ramp to where the car lands. This “jump distance” can be compared with the mathematical predictions.
 - Place a ruler in a vertical orientation about mid-way between the end of the ramp and where the car lands. Estimate the height of the jump and compare it to the “height distance” prediction.

Academic Extension/Modification:

The above activities assume a constant acceleration. Real vehicles shift gears and have variable acceleration curves. If acceleration values for each gear in a typical car can be obtained (and are approximately constant in a gear), the velocity-time graph has several discontinuities at which the slope (and therefore acceleration) changes. The number of discontinuities equals the number of gearshifts. This more realistic data permits computation of the net force as a step function. Further, for Physics classes taking a calculus approach, real acceleration curves (that are non-linear) can be analyzed using derivatives.

Writing Prompts/Potential Discussion Questions:

- Upon inspection, the ticks on the ticker-tape time become increasingly spread out. What does this indicate about the velocity?
- Upon more careful inspection, the space between successive pairs of ticks on the ticker-tape timer increases, but by a constant amount. What does this indicate about the acceleration? About the net force?
- As a cart rolls down an incline, it accelerates. What force is the cause of this acceleration?
- As a Monster Truck shifts gears, its acceleration increases in a non-linear manner. What does this indicate about the Truck's acceleration? What does that indicate about the net force? What is the source of the force responsible for the acceleration?
- When computing the distance a Truck travels when it jumps off of a ramp, you should compute the height of the jump first. Why?



ENERGY: IT HAS TO GO SOMEWHERE

Objectives:

Students will identify sources of friction in a Monster Truck (engine, drive train components, road surface, and wind resistance) and the energy content (potential energy) of methanol from the Handbook of Chemistry and Physics. Using those values, students will compute the work done by a Monster Truck engine. Students will also compute the amount of energy lost to friction and heat losses. Finally, students will compute the efficiency of a Monster Truck.

Curriculum Connection:

The Law of Conservation of Energy holds that the total energy before and after an event remains the same. This provides a much easier way to measure friction, a major concern in any machine.

In a Monster Truck engine, chemical potential energy in methanol gets converted into the mechanical energy of pistons, then into rotational energy of the drive train, then into rotational energy of the wheels, and finally into kinetic energy of the Truck (less friction of the tires with the road, wind resistance, friction in drive train components, and the energy lost in tailpipe emissions). Students will first calculate the energy content of a gallon of methanol, which is the initial potential energy. They will then calculate the work done by a Monster Truck engine. If these values differ, the loss is due to friction and energy lost via tailpipe emissions. The ratio between the work and the energy content of methanol leads to an efficiency computation ($= \text{work/energy of the methanol}$).

Note: Students will need to have a working knowledge of reciprocating engines and drive train components to identify how the engine works and where friction arises. You can use the reproducible to review energy transfers and losses to facilitate their understanding.

Class Time:

50 minutes

Materials Needed:

None

Lesson Steps:

1. **Using the following values, have students calculate the mileage of a Monster Truck (miles/gallon of methanol).** This can be computed by dividing the typical number of miles a Monster Truck travels on a tank of fuel ($d = 3$ miles) by the number of gallons the fuel tank holds ($g = 20$ gallons of methanol).
2. **Students should convert the mileage expressed as miles/gallon to meters/mole of methanol.** The distance in miles can be converted to meters by the following conversion: distance in meters = distance in miles \times 1610. The number of gallons of methanol can be converted to moles of methanol by the following conversion: methanol in moles = methanol in gallons \times 93.47.
3. **Prompt students to find the heat of combustion for a mole of methanol ($\Delta H_c = -726.34$ kJ/mole), then have them compute the chemical potential energy in a tank of Monster Truck fuel [$PE = (\Delta H_c) \times$ (number of moles of methanol in the fuel tank)].**

Important Terms: Law of Conservation of Energy, kinetic energy, potential energy, work

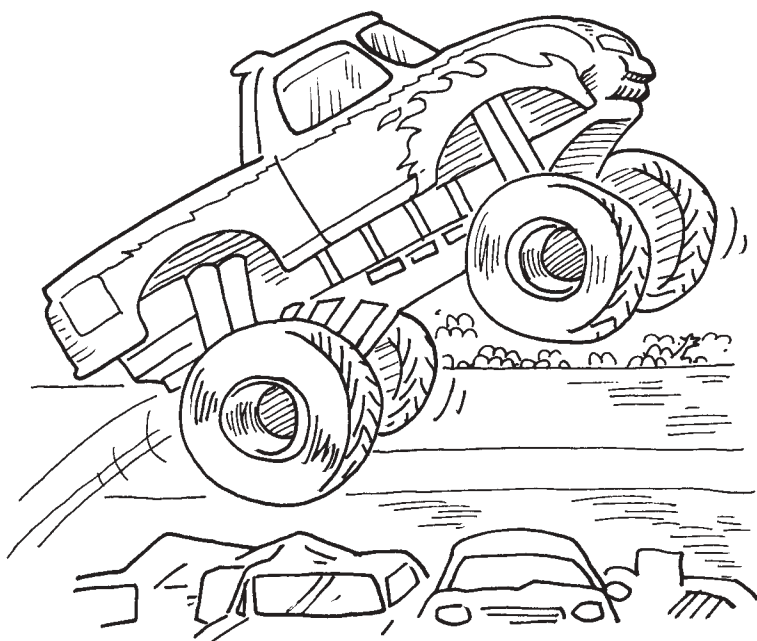
Exhibit Link:

This lesson is best used as a post-exhibit activity. The Monster Truck drive train section of the exhibit will provide a valuable way for students to experience and discover the inner workings of a Monster Truck—the same inner workings that are at the heart of this lesson.

4. **Given the distance a Monster Truck can travel on a tank of fuel (=d, in Step 1) and the motive force of a Monster Truck engine (approx 45,000N), students will calculate the work done by a tank of fuel ($W = F_{\text{engine}} \times d$).**
5. **Ask a student to state the Law of the Conservation of Energy.** Then have students compare the PE and work they computed for a Monster Truck. Since these values will differ (less work), ask students to explain why that might be. (Answer: energy losses due to friction, wind resistance, etc.)
6. **As a conclusion, have students calculate the efficiency of a Monster Truck engine using the formula (efficiency = Work/PE).** This number will be less than 1.0. Usually, efficiency is expressed in percent. To convert the ratio Work/PE to percent, multiply by 100.

Academic Extension/Modification:

Students can explore the effects of lubrication on the friction losses in the engine and drive chain components. Alternately, students can explore changes in a Monster Truck shape that might improve wind-resistance.



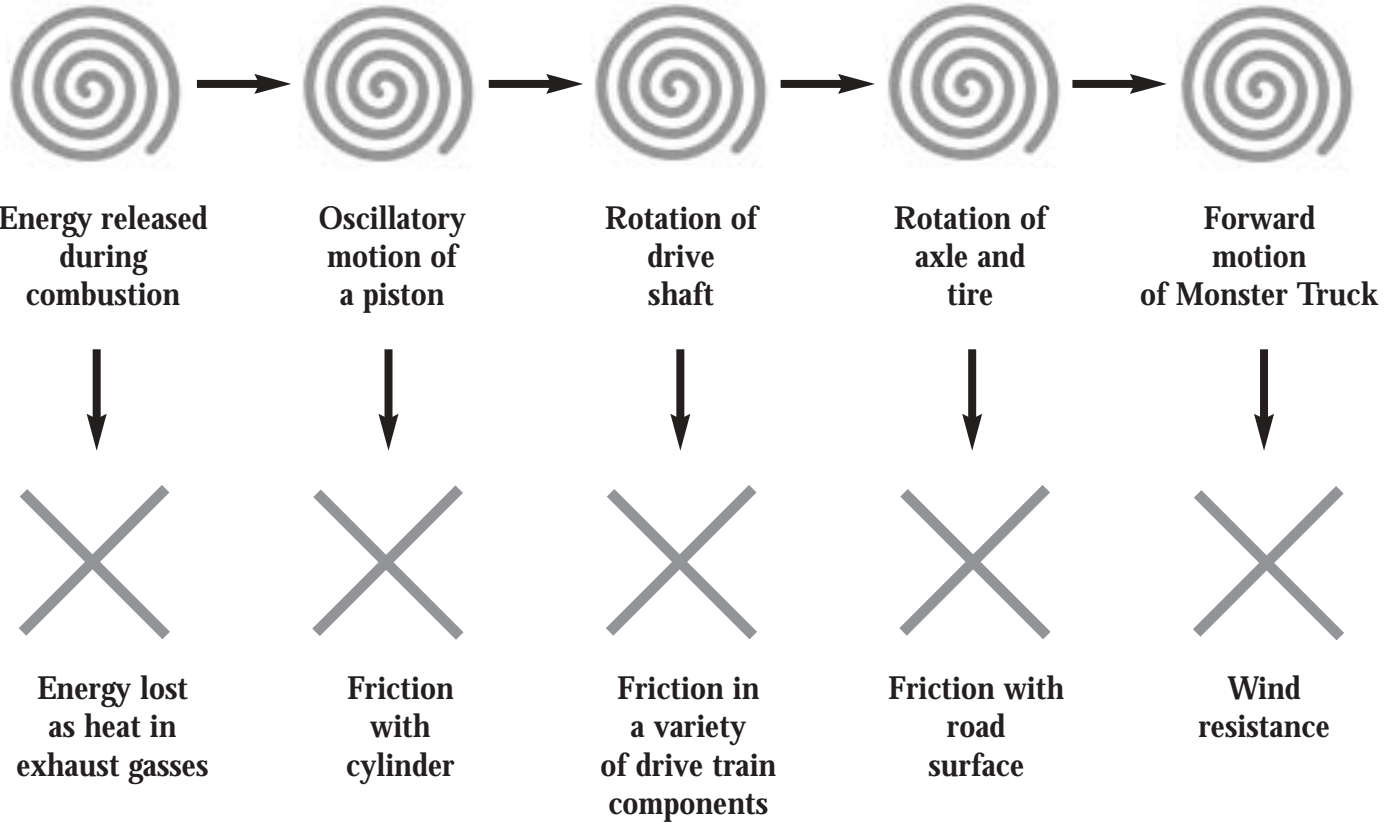
Writing Prompts/Potential Discussion Questions:

1. Methanol molecules store chemical potential energy in chemical bonds. Given knowledge of chemistry, how is this energy stored?
2. Typically, combustion of any fuel is incomplete and leads to pollution. This also reduces the potential energy available to make a vehicle move. How can testing tailpipe emissions be used to better compute the available potential energy?
3. Monster Trucks are more efficient than passenger cars. What variables make this possible?



Energy Transfers and Losses

Energy Transfers



Energy Losses

• TONS O' TORQUE

Objective:

Students will calculate the moments of inertia and average angular accelerations of a Monster Truck drive shaft and tire in order to compute the torque acting on each. As an extension, students can compute the forward speed of a Monster Truck given the RPM of a Monster Truck terra tire and its radius.

Curriculum Connection:

This lesson provides an excellent supplemental activity to a physics of rotation focus. The lesson enables students to explore the concept of torque, particularly as it applies to Monster Trucks. After some quick demonstrations of torque outside of an automotive context, students will arrive at a working definition of the term, understanding that it can result in the rotation of an object. From there, students will explore how several theoretical physics concepts are applied to real systems (such as Monster Trucks).

Class Time:

50 minutes

Materials Needed:

- socket wrench
- nut/bolt (a seesaw, triple beam balance, or screw drivers where the diameter of the handles vary can be substituted)

Lesson Steps:

This lesson is comprised of three parts. **Part 1** is a demonstration of torque. **Part 2** calculates the torque acting on a Monster Truck drive shaft. **Part 3** calculates the torque acting on a Monster Truck tire.

Part 1: The concept of torque can be demonstrated in any number of ways. One convenient way involves a socket wrench. To demonstrate the concept of torque to your class:

1. **Present a nut tightened on a bolt to each student in your class.**
2. **Allow each student to use the socket wrench to loosen the nut.** The first time this is attempted, the wrench should be held towards the end. Students will observe that it requires only a little force to loosen the nut.
3. **Retighten the nuts and have each student repeat this exercise but by holding the wrench much closer to the bolt.** Students will observe that this is much harder.
4. **Use these observations to make several points:** If the force is applied close to the bolt (short moment arm), students will observe that the nut can be turned only with difficulty, indicating a high torque. If the force is applied towards the end of the wrench handle, less force is required, indicating a lower torque. Another good way to demonstrate this concept is to have students try to push open a door by pushing on the handle. Then they should try to push open the door by exerting a force closer to the where the door is hinged. The same result can be observed.

Important Terms: angular acceleration, angular momentum, angular velocity, moment of inertia, torque

Exhibit Link:

This lesson is best covered after visiting the exhibit, as it requires a working knowledge of engine and drive train components. The exhibit Shop area includes a Monster Truck Drive Train for visitors to experience and discover the inner workings of a Monster Truck.

Part 2: In this section, students will calculate the torque (τ) acting on the drive shaft of a Monster Truck using the equation ($\tau = I\alpha$), where I is the moment of inertia of a rotating shaft ($I = MR^2/2$ where M = the mass of a drive shaft and R = the radius of the drive shaft) and α is angular acceleration.

1. **Given values of $M = 13.61$ kg and $R = 0.04$ m, instruct students to compute the moment of inertia for a drive shaft.**
2. **Explain to students that the average angular acceleration can be calculated by this equation:**

$$a = (v_f - v_i)/t$$

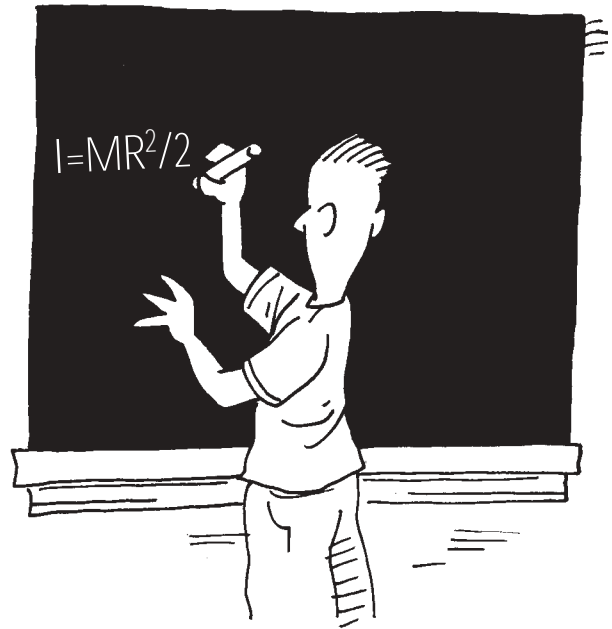
where " v_i " is the initial angular velocity [= 2π (RPM_{driveshaft}/60 seconds)] when shifting from one gear to the next (approx. 1500RPM);

" v_f " is the final angular velocity

[= 2π (RPM_{driveshaft}/60 seconds)] when shifting from that gear to the next; (approx. 8500 RPM);

and " t " is the time to accelerate from one gear to the next (approx. 5.5 seconds).

3. **Give your students values for RPM_{driveshaft} and " t " and have them compute the average angular acceleration.**
4. **Using the values computed in Steps 1-3, have your students calculate the torque acting on the driveshaft.**



Part 3: In this final section, students can calculate the torque acting on a tire of a Monster Truck. Be sure to ask students why it is necessary to calculate both the torque of the drive shaft and the torque of a tire (a brief explanation of the interaction of the two may be necessary.)

1. **Given the radius and mass of a Monster Truck tire ($M = 800$ lbs or 361.99 kg, $R = 33$ inches or 8.38×10^{-1} m), students should now calculate the moment of inertia for a Monster Truck wheel ($I = MR^2/2$).**

2. **The average angular acceleration of a tire should then be calculated by this equation:**

$$a = (v_f - v_i)/t$$

where " v_i " is the initial angular velocity [= 2π (RPM_{tire}/60 seconds)] when shifting from one gear to the next (0 RPM at 0 mph);

" v_f " is the final angular velocity [= 2π (RPM_{tire}/60 seconds)] when shifting from that gear to the next; (304.1 RPM at 60 mph);

and " t " is the time to accelerate from 0 mph to 60 mph (approx 4.5 seconds).

3. **Using the values computed in Steps 1-2, students should calculate the torque acting on the wheel.**

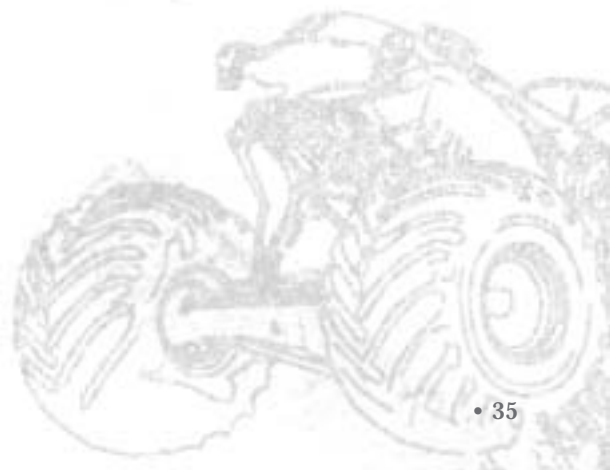
Academic Extension/Modification:

Advanced students can be asked to compute the forward speed of the Monster Truck using the following approach:

At a particular speed (70 mph), a Monster Truck tire rotates at 354.8 RPM and has a radius of 8.38×10^{-1} m. The circumference of the tire will be computed using $C = \pi \times 2r$. The circumference can be multiplied by the RPM_{tire} to obtain the distance traveled in one minute. The distance (in meters) traveled in an hour can be computed by multiplying the distance by 60. Students can convert this distance to miles/hour by dividing by 1610.

Writing Prompts/Potential Discussion Questions:

1. Given that pistons go up and down, speculate on how the oscillatory motion of pistons is used to make the camshaft rotate.
2. Given that the drive shaft runs the length of a vehicle, how is the rotation of the shaft transferred to the motion of a wheel that rotates on an axle perpendicular to the drive shaft?



THE PHYSICS OF COMBUSTION

Objectives:

Given the dimensions of a Monster Truck piston, students will compute the volume before and after the compression stroke and the change in temperature of the gas (Combined Gas Law). Then, given the combustion reaction of the engine and the energy released, students will note the change in volume and temperature. Students will also learn to compute the work done by a piston ($W = P \Delta V$).

Curriculum Connection:

This teacher-directed lesson provides a good review of key concepts such as thermodynamics, the Ideal Gas Law, heat capacity, work, and energy. For this lesson students must first be introduced to a simple view of the four-stroke engine (intake, compression, power, exhaust). The interesting physics angle is in the compression and power strokes. Students will first explore a compression stroke's role in the process of combustion, including how it illustrates the First Law of Thermodynamics and how some energy is lost to friction.

Next, students will examine the power stroke. Assuming complete combustion, the chemical reaction is:



After developing a working knowledge of this chemical reaction as it pertains to combustion, students can calculate the work done in the power stroke ($W = P \Delta V$). They will deduce that the difference between the actual work and the potential energy in a cylinder of methanol and air mixture can be explained only by a loss of energy due to friction between the piston and cylinder or heat loss in exhaust gasses.

Class Time:

50 minutes

Materials Needed:

None

Lesson Steps:

Note: A brief description of how a four-stroke engine works will be helpful before beginning the lesson steps. This can be done by drawing a Pressure versus Volume diagram on the board and briefly explaining the Carnot cycle. For the purposes of this lesson, the values of a Monster Truck piston have been estimated.

Part 1: Compression Stroke: After the cylinder is filled with a mixture of methanol and air (intake), the piston moves to the top of the cylinder, compressing the gas mixture. This compression causes a rise in temperature in the cylinder.

1. Instruct students to use the Combined Gas Law below to compute the increase in temperature:

$$P_1V_1/T_1 = P_2V_2/T_2$$

Important Terms: adiabatic process, Carnot engine, coefficient of kinetic friction, Combined Gas Law, four-stroke engine, First Law of Thermodynamics

Exhibit Link:

This lesson serves as an excellent pre-exhibit activity, as it helps students understand what is happening behind the scenes of a drive train. The exhibit's Shop area can then provide a look into these components of a Monster Truck.

The values on the left are initial values (when the piston is at the bottom of its compression stroke) and values on the right are final values (when the piston is at the top of the compression stroke). Supply the following values:

$P_1 = 1$ atmosphere

$V_1 = 1.11$ L (volume of cylinder at the beginning of the compression stroke)

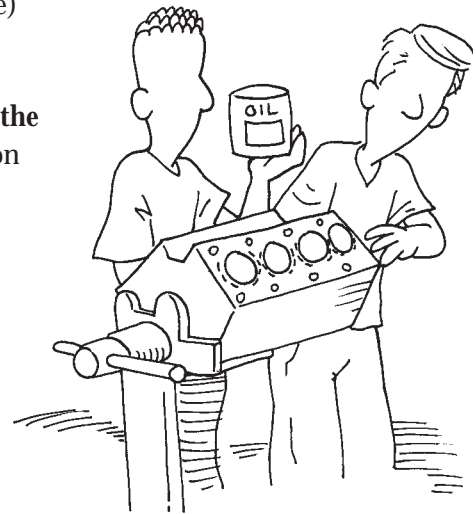
$T_1 = 295^\circ$ A (room temperature)

$P_2 = 13.6$ atmospheres (the exhaust pressure)

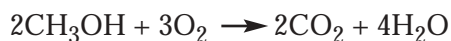
$V_2 = 0.09$ L (volume of cylinder at the end of the compression stroke)

$T_2 =$ a value to be calculated by the student

2. **Direct students to observe the increase in temperature and ask for the effects of this rise.** (Answer: the efficiency of the combustion reaction is greatly increased.)



Part 2: Power Stroke: When the mixture is ignited (by a spark), a **great** percentage of the mixture is combusted, increasing the amount of energy converted from a chemical form (bonds in the methane and oxygen molecules) to kinetic energy of the piston. Assuming complete combustion, the chemical reaction is:



1. **Write the reaction above on the board and instruct students to note the increase in the number of moles of gas** (from 5 moles of reactants to 6 moles of products).
2. **Note that the reaction releases heat, thus increasing the temperature of the gas.** If available, have students look up the heat of combustion for the reaction in the Handbook of Chemistry and Physics. Assuming that about 5.5×10^{-2} moles of fuel are used per power stroke and the heat released in the combustion (ΔH_c) = -726.34 kJ/mole, have students compute the energy released on each power stroke using the formula:

$$\text{energy released} = Q = 5.5 \times 10^{-2} \times \Delta H_c$$

3. **Students should then use the heat capacity equation ($Q = mc \Delta T$) to calculate the increase in the temperature after combustion.** Supply the following values:

Q = the heat released in the combustion, calculated in **Step 2**

$m = 4.37$ grams (the mass of the exhaust gasses per power stroke)

$c = 0.32$ kcal/kg $^\circ\text{C}$ (specific heat of the weighted average [in a ratio of 2:4—obtained from the stoichiometry of the combustion reaction] for carbon dioxide and steam)

$\Delta T = ?$ (the change in temperature of the air/methanol mixture before combustion and the carbon dioxide/steam mixture after combustion, to be computed by students)

4. **The change in temperature ($=\Delta T$) equals $T_{\text{final}} - T_{\text{initial}}$, where T_{initial} equals T_2 computed by students in Part 1.** Since they have just calculated the value of ΔT , students will calculate T_{final} .
5. **Because the expansion of gasses in a power stroke occurs so rapidly, the process is nearly adiabatic.** Hence the heat (Q) lost to the system is nearly zero.

The First Law of Thermodynamics is:

$$\Delta U = Q - W$$

where ΔU is the change in internal energy of the cylinder, Q is the heat added or removed to the system and W is the work done on the piston. Ask students to restate the first law as it applies to adiabatic processes.
(Answer: $\Delta U = -W$)

6. If $\Delta U = -W$ (negative means work is being done by the system) by determining ΔU , we have found the work done in the power stroke. Students should compute the work done by a piston in a power stroke using the equation ($W = P \Delta V$), where P is the pressure (P_2) computed in **Part 1**, and ΔV is the difference in volumes in that same step.

Academic Extension/Modification:

Students can explore how lubricants reduce the coefficient of kinetic friction, thus improving engine efficiency and reducing engine wear. Alternately, they can consider the extent to which a real engine deviates from an ideal Carnot engine.

Writing Prompts/Potential Discussion Questions:

1. A Monster Truck engine is more efficient than a passenger car engine. How do the efficiencies compare with each other? How do the efficiencies of both types of engines compare to an ideal Carnot engine? Use the following equation and data table to compute the efficiency of a Carnot engine acting at the same operating temperatures in each vehicle:

(Note: the values used below have been estimated.)

$$\text{Efficiency} = 1 - T_L/T_H$$

Temperature Differences for Carnot Comparisons

	Blue Thunder	Mazda Protege
Low operating temp	295° A	295° A
High operating temp	462° A	420° A

2. Some of the energy of the combustion reaction is lost because the exhaust gasses have such a high temperature. How much energy is lost to exhaust products?
3. Some of the energy of the combustion reaction is lost to friction between the piston and the walls of the cylinder. How does lubrication reduce this friction?

Glossary

acceleration: a change in the direction or magnitude (speed) of an object.

average acceleration: can be computed with this equation: $a = (v_f - v_i)/t$, where “a” is the acceleration, “ v_i ” is the initial speed, “ v_f ” is the final speed, and “t” is the time it takes to change speed.

active restraint: a type of safety equipment activated by the vehicle passenger, designed to restrict the movement of drivers and/or passengers. (ex. seat belt, child safety seat restraints)

adiabatic process: a thermodynamic process in which no heat is lost or gained. The power stroke in an engine occurs so rapidly that little heat is lost; therefore, the power stroke is considered an adiabatic process.

angular acceleration: the change in angular velocity divided by time.

angular momentum: the product of the moment of inertia and its angular velocity.

angular velocity: for rotating objects, the amount of rotation expressed in radians/time.

BDC: the measurement of a piston at the bottom of its travel in the cylinder.

bore: the diameter of a cylinder in an engine.

camshaft: the component that controls the opening and closing of valves in an engine.

capacity: the amount a container or object can hold or contain; e.g., the amount of fuel a Monster Truck’s fuel tank can hold.

Carnot engine: an ideal engine in which each process is reversible.

circumference: the distance around a circle.

coefficient of friction: the ratio of the force of friction to the normal force when one surface is sliding (or attempting to slide) over another surface.

Combined Gas Law: expression relating pressure, volume, and temperature before and after an event when the moles of gas remain constant: $P_1V_1/T_1 = P_2V_2/T_2$.

consume: to take in or use up; burn, as an automobile engine burns fuel to move a vehicle.

crankshaft: device that changes the reciprocating motion of the pistons to rotating motion; contains the area where the connecting rods are fastened and also the area where the flywheel and engine drive pulley are connected.

customary system of measurement: a measurement system used in the United States, which includes basic units such as feet and gallons.

dashboard: the panel under a vehicle’s front windshield, on which an automobile’s fuel gauge and other control instruments display.

diameter: a line segment that passes through a circle’s center to connect two points on the circle.

displacement: the distance between two points. In auto technology, the volume that a piston displaces in a cylinder as it moves from TDC to BDC.

distance: the straight-line measurement between two points.

engine block: the metal foundation containing the parts of an internal-combustion engine; includes cylinders, coolant passages, oil passages, etc.

exhaust valve: the valve that opens to allow all the vapors inside the cylinder to be removed from the engine on the exhaust stroke.

eye wash station: the area in a lab specifically designed for washing any foreign matter from the eyes; a station can be plumbed into the water system or may use separate bottles of saline solution.

fire extinguisher: hand-held fire fighting equipment designed with specific chemicals to put out small fires.

First Law of Thermodynamics: the change in the internal energy of a system equals the difference between the heat added to the system and work done by the system.

four-stroke engine: an internal-combustion engine developed by Nikolaus Otto in 1867. A four-stroke engine works as follows: as a piston moves down, the intake valve(s) opens, allowing a mixture of fuel and air to flow into the cylinder (intake stroke). After the intake valve(s) closes, the piston moves upwards, compressing the mixture and increasing its temperature (compression stroke). If this mixture is ignited, the piston is driven downwards, making the drive shaft rotate (power stroke). Lastly, the piston moves upwards while the exhaust valve(s) opens, allowing exhaust gasses to be pushed out of the cylinder.

gauge: a measuring device.

horsepower: the measurement of the engine’s ability to perform work.

intake valve: valve that opens to allow fuel and air to be drawn into the combustion chamber.

jack stands: safety devices designed to be placed under a vehicle that has been jacked up to prevent the vehicle from falling while work is being performed.

kinematics: the description of motion in terms of distance, speed, velocity, and acceleration.

kinetic energy: the energy an object has due to its motion.

Law of Conservation of Energy: states that the total energy in a system both before and after a process is constant.

Law of Conservation of Momentum: In an isolated system, if the momenta of two objects are measured before and after colliding, the total momenta will be the same.

Material Safety Data Sheets (MSDS): information provided by chemical manufacturers that have instructions on how to protect users and the environment in case of a spill; also contains instructions on how to clean up and dispose of material that has been spilled.

metric: the decimal-based measurement system used most often in the United States during scientific pursuits; basic units include meters and liters.

moment of inertia: the product of the mass of a rotating object and its radius squared. The exact equation depends on the shape of the object, but for drive shafts or tires, it is given by this equation: $MR^2/2$ where M is the mass of the rotating object and R is its radius. The moment depends on the mass of the rotating object and on how far from the axis of rotation the mass is. If the mass is close to the axis of rotation, the moment is small. If the mass is far from the axis of rotation, the moment is large.

momentum: the product of an object's speed and its mass; $p = mv$. (plural: **momenta**)

net force: the sum of all the forces acting on an object.

passive restraint: a type of safety equipment designed to restrict the movement of drivers and/or passengers; activates automatically to protect the occupant of a vehicle. (ex. air bags, automatic shoulder harness)

pi: a ratio of a circle's circumference to its diameter, equal to about 3.14 (or 3).

piston stroke: the movement of the piston from the bottom of its travel to the top of its travel.

piston: the component in an engine that is driven up and down in the cylinder and is connected to the crankshaft by the connecting rod.

potential energy: the energy an object has due to its position.

projectile motion: the motion of an object in a gravitational field.

radius: a line segment that connects a circle's center to any point on the circle; it is half the size of the diameter.

rate: the measure of how fast something is changing; when the distance an object moves is divided by the time it takes to travel that distance, the quotient equals the object's average rate of speed, e.g. feet per second.

spark plugs: devices that, upon receiving power, ignite the fuel/air in the combustion chamber causing the piston to move down in the cylinder, and thus causing the crankshaft to turn.

speed: the rate of change in an object's position over time (speed = distance/time).

Supplemental Restraint System (SRS): restraints designed to help keep drivers and passengers in their respective seats in the event of an accident. (ex. air bags)

TDC: the measurement of the piston at the top of its travel in the cylinder.

timing chain or belt: a device that coordinates the movement of the crankshaft with the camshaft to ensure that pistons and valves are working together.

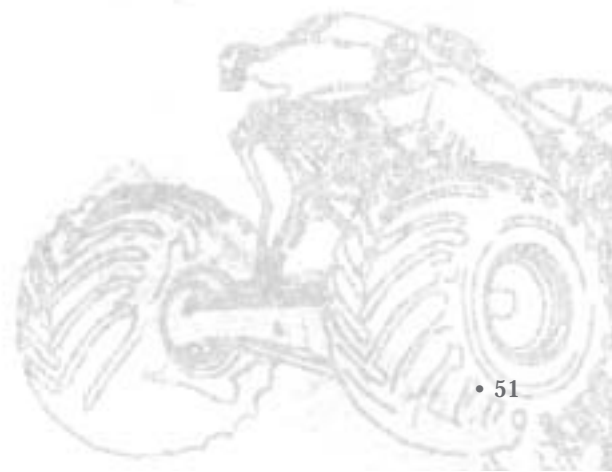
torque: a force applied to some point other than the center of an object's mass, causing movement or rotation.

unibody design: a chassis design that includes a floor pan and a small sub frame section in the front and rear.

variable: a quantity that may have more than one value.

velocity: speed in a particular direction. (e.g., 50 mph due north) If an object does not change its direction of motion, then its speed is the same as its velocity.

work: the transfer of energy to a body by the application of a force that moves the body in the direction of the force ($W = Fd$).



Additional Resources and Web Sites

Teacher References

Giancoli, Douglas. *Physics: Principles with Applications*. 2nd Edition. © 2000-2001 by Prentice Hall Inc.

Halliday, D., Resnick, R., & Walker. *Fundamentals of Physics*. 5th Edition. © 1997 by John Wiley & Sons, Inc.

Hewitt, P. *Conceptual Physics*. 8th Edition. © 1998 by Benjamin Cummings.

Zitzewitz, P. *Glencoe Physics: Principles and Problems*. © 2002 by Glencoe/McGraw Hill.

Monster Truck Racing by Scott D. Johnston (Capstone Press, 1994)

This book is a clear, concise, and colorful introduction to Monster Truck racing for grades 4-6 students. The author describes the history, science, economics, and sport of Monster Truck racing. The book includes many photographs, a glossary, and a list of additional resources.

Web Sites

<http://www.getbehindthewheel.com/index.htm>

This web site includes links to the web sites of automotive corporations, whose sites include detailed information about dozens of automobiles, including photographs you might wish to show students when discussing vehicles' relative fuel capacities.

<http://www.its-about-time.com>

Visit this site to learn more about the popular textbook line Active Physics and other supplemental kits available to teach math and science concepts to grades 6-12.

<http://www.monstermania.com>

Find information about upcoming events, Monster Mania news, and links to Monster Truck Home pages here.

<http://monstertruckracing.com>.

Access high-quality photographs of all your favorite trucks, plus read Truck facts and stats.

<http://www.physicsclassroom.com/>

A good resource for learning basic physics concepts and reviewing them in a Physics Tutorial. Also includes practice problems and a multimedia section where students can view physics in action.

<http://www.sciencejoywagon.com/physicszone/>

The Physics Zone presents introductory level, algebra-based physics concepts in a multimedia format that is engaging as well as informative.

<http://www.truckworld.com/index.html>

Read monthly articles written by experts and view the Show and Events section for all the latest results.

<http://ushra.com/#>

Official site of the USHRA, this resource provides current Monster Truck results, a photo gallery, official news and headlines, driver bios and more. A true Monster Truck fan must-see!