Learning Cycle Five

Ready, Set, GO!

5

Ready, Set, GO!

Introduction

The goal for this learning cycle is to have students explore the concept of torque and gear trains. They will begin to understand gear ratios and how to increase and decrease the torque of a small electric motor. After completing this learning cycle, students will be ready to work for the remainder of the nine-week period on their solutions to the *Primary Challenge.*

Objectives and Essential Questions

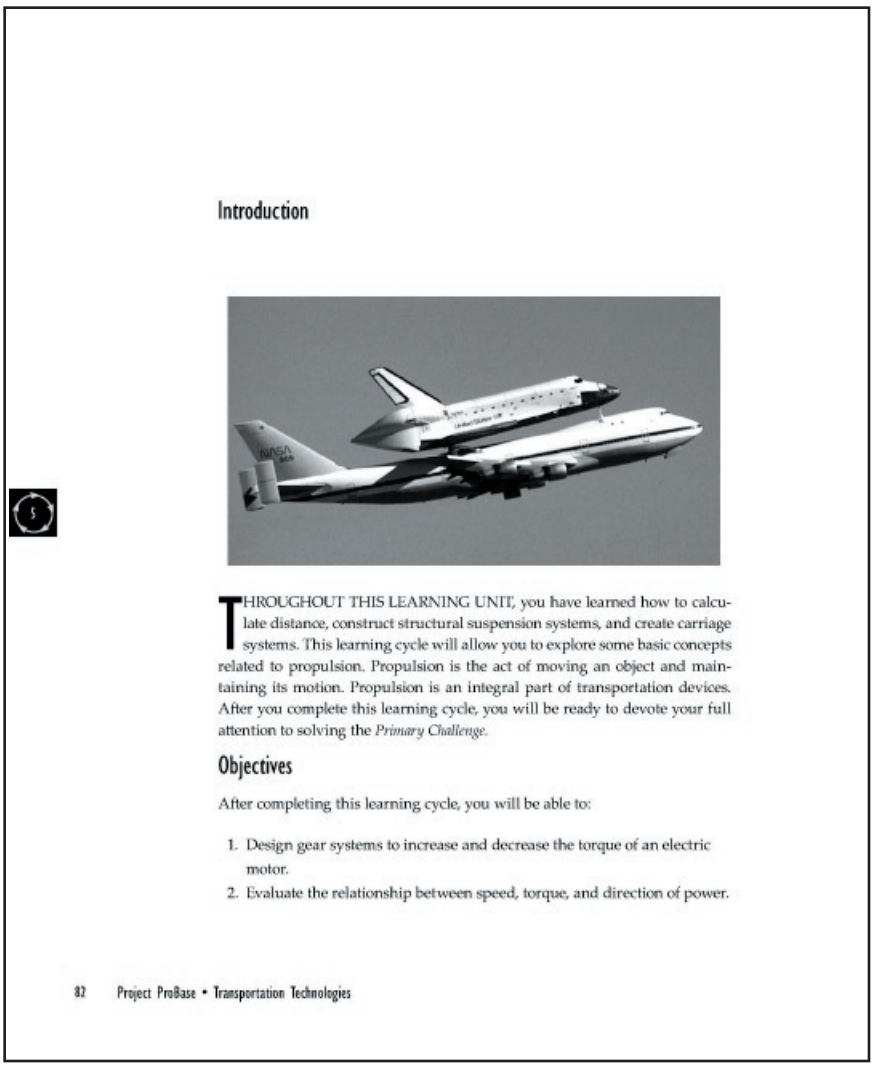
After completing this learning cycle, students will be able to:

1. Design gear systems to increase and decrease the torque of an electric motor.

Essential Question 9a: How are technologies used to control devices or systems and provide information to humans?

2. Evaluate the relationship between speed, torque, and direction of power.

Essential Question 7f: How can the establishment of relationships, controlling variables, categorizing techniques, and making inferences aid in the development of new technological designs?



Introduction

THROUGHOUT THIS LEARNING UNIT, you have learned how to calculate distance, construct structural suspension systems, and create carriage systems. This learning cycle will allow you to explore some basic concepts related to propulsion. Propulsion is the act of moving an object and maintaining its motion. Propulsion is an integral part of transportation devices. After you complete this learning cycle, you will be ready to devote your full attention to solving the *Primary Challenge.*

Objectives

After completing this learning cycle, you will be able to:

1. Design gear systems to increase and decrease the torque of an electric motor.
2. Evaluate the relationship between speed, torque, and direction of power.

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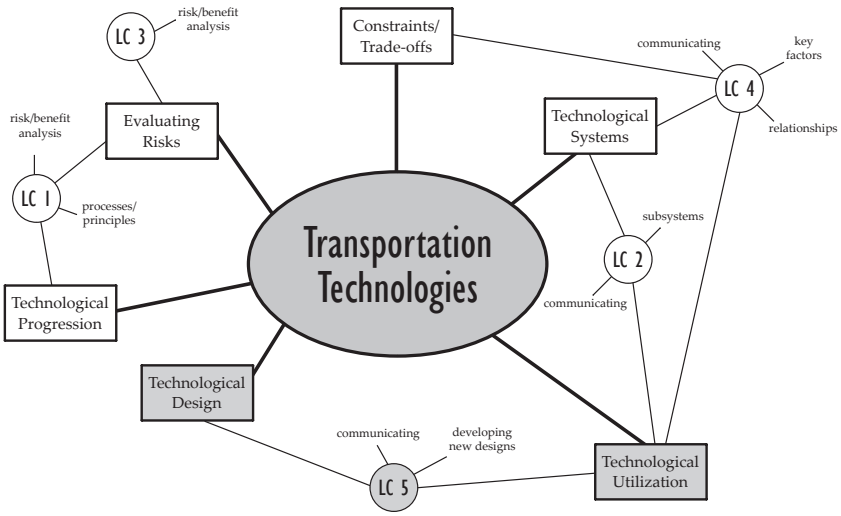
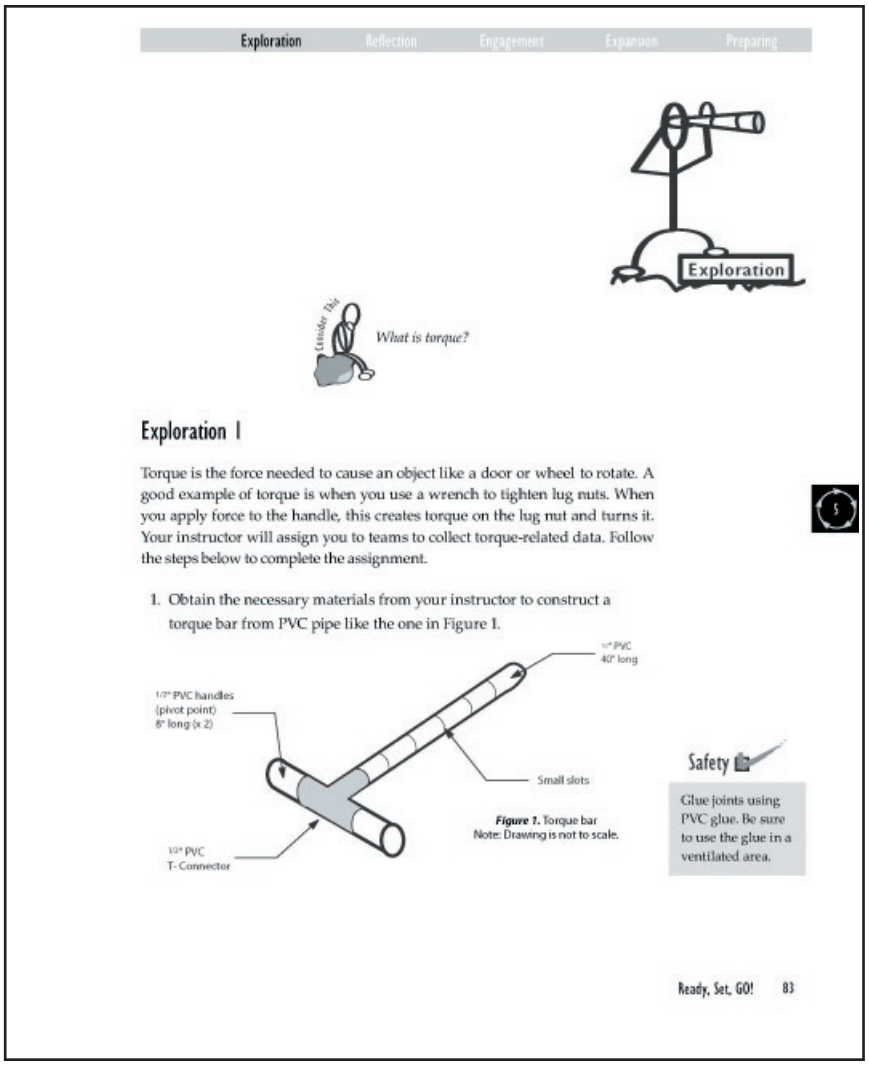
Transportation Technologies
Learning Cycle Five Concept Map





Exploration Reflection Engagement Expansion Preparing

Exploration

Consider This

What is torque?

Exploration I

Torque is the force needed to cause an object like a door or wheel to rotate. A good example of torque is when you use a wrench to tighten lug nuts. When you apply force to the handle, this creates torque on the lug nut and turns it. Your instructor will assign you to teams to collect torque-related data. Follow the steps below to complete the assignment.

1. Obtain the necessary materials from your instructor to construct a torque bar from PVC pipe like the one in Figure 1.

Figure 1. Torque bar
Note: Drawing is not to scale.

Safety

Glue joints using PVC glue. Be sure to use the glue in a ventilated area.

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Facility Requirements

Explorations I and *II* work best in classrooms with tables large enough to allow students to work in small teams. The *Engagement* activity works best in a general laboratory equipped with basic tools and equipment such as hand tools, drill press, table saw, band saw, etc.

Equipment and Materials

Based on a class of 28 students:

45 feet of ½" PVC pipe

(9) ½" PVC T-connectors

Hack saw

1,000 gram weight (e.g., bucket of water or sand, stack of metal washers)

PVC glue

(9) Gear Box and Motor Kits - providing multiple gear box configurations

(9) AA batteries

(9) AA battery holders

(38) Wheels – 1⅝" diameter

(38) Wheels – 3" diameter

(9) Slide switches - 0.5A DC/3A AC - 36" of 1⅛" welding rod for wheel axles

(9) ¼" eye screws

(9) Spring scales (with a capacity of 5 Newtons)

Various materials specified by design solutions in the *Engagement* activity.

Suggested Daily Outline

Day One	Day Two
Introduction, *Exploration I*	*Exploration I* *Reflection*
Day Three	**Day Four**
Exploration II	*Exploration II* *Reflection*
Day Five	**Day Six**
Engagement	*Engagement*

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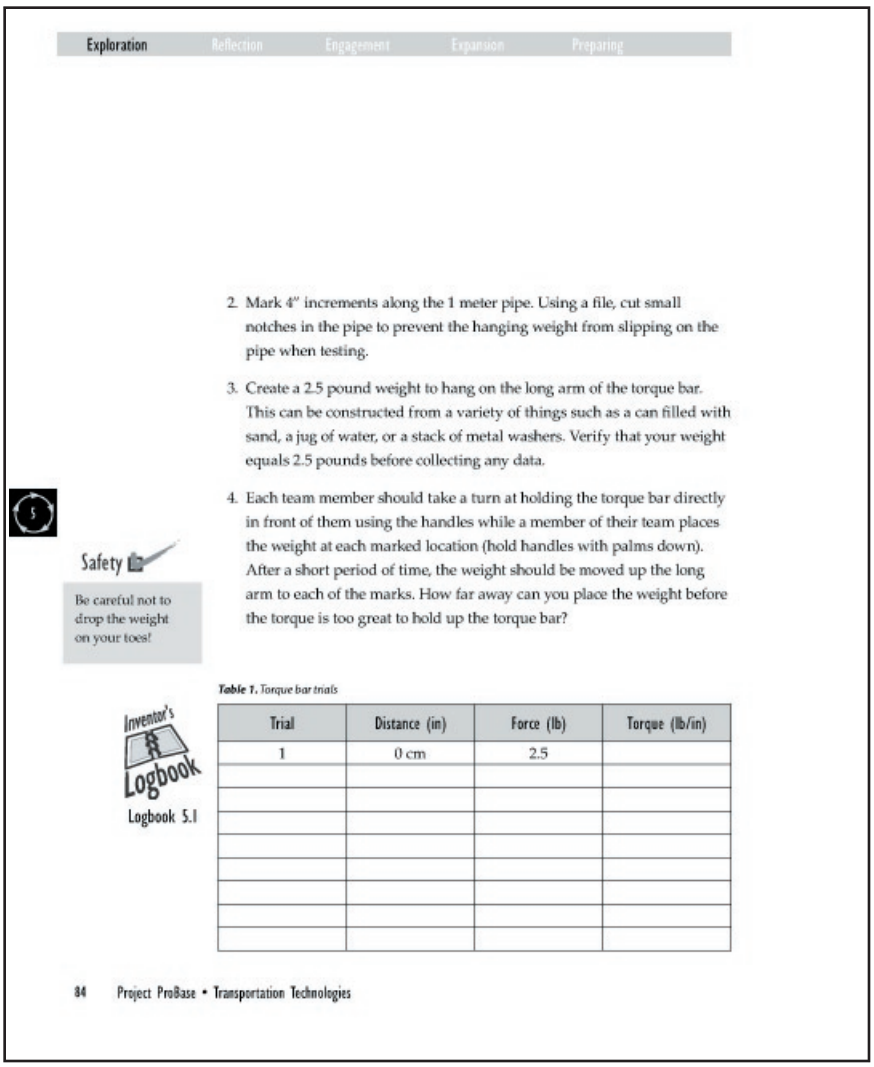
Estimated Number of 50-minute class periods: **6**



Exploration Reflection Engagement Expansion Preparing

2. Mark 4" increments along the 1 meter pipe. Using a file, cut small notches in the pipe to prevent the hanging weight from slipping on the pipe when testing.
3. Create a 2.5 pound weight to hang on the long arm of the torque bar. This can be constructed from a variety of things such as a can filled with sand, a jug of water, or a stack of metal washers. Verify that your weight equals 2.5 pounds before collecting any data.
4. Each team member should take a turn at holding the torque bar directly in front of them using the handles while a member of their team places the weight at each marked location (hold handles with palms down). After a short period of time, the weight should be moved up the long arm to each of the marks. How far away can you place the weight before the torque is too great to hold up the torque bar?

Safety

Be careful not to drop the weight on your toes!

Inventor's Logbook

Logbook 5.1

Table 1. Torque bar trials

Trial	Distance (in)	Force (lb)	Torque (lb/in)
1	0 cm	2.5	

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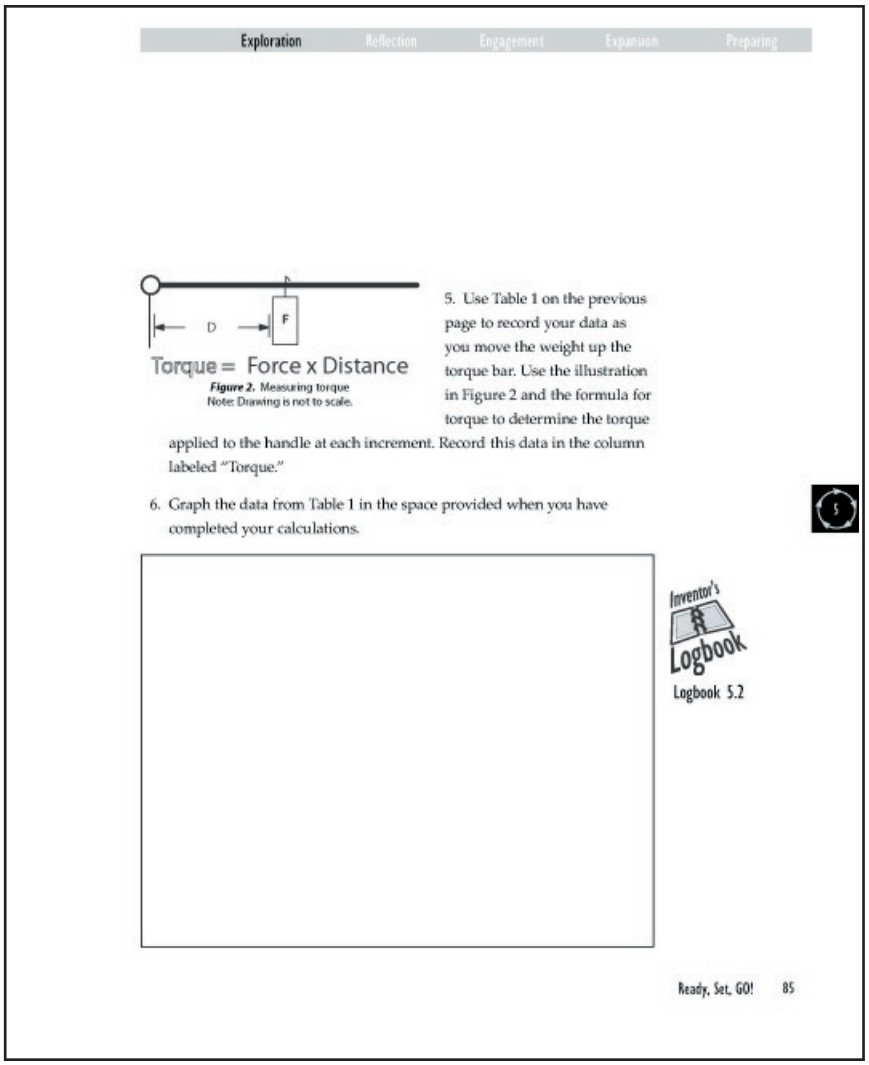
Exploration I

The *Exploration I* phase has the students construct a device (Figure 1) that will allow them to kinesthetically experience the concept of torque.

Teaching tips

Assign students to small teams of three or four and allow them to construct the torque bar following the illustration in the student text. Encourage each student to experience this activity. Remind students to record the data in Table 1 in the student text.



Exploration Reflection Engagement Expansion Preparing

Figure 2. Measuring torque
Note: Drawing is not to scale.

5. Use Table 1 on the previous page to record your data as you move the weight up the torque bar. Use the illustration in Figure 2 and the formula for torque to determine the torque applied to the handle at each increment. Record this data in the column labeled "Torque."

6. Graph the data from Table 1 in the space provided when you have completed your calculations.

Inventor's Logbook

Logbook 5.2

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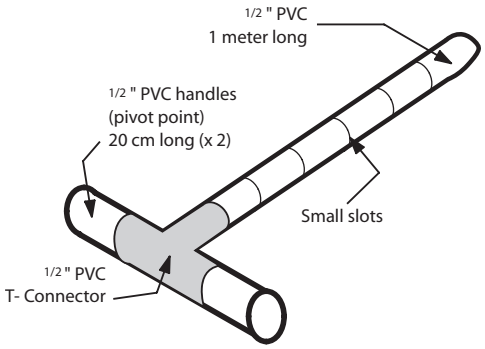


Figure 1. Torque bar
Note: Drawing is not to scale.

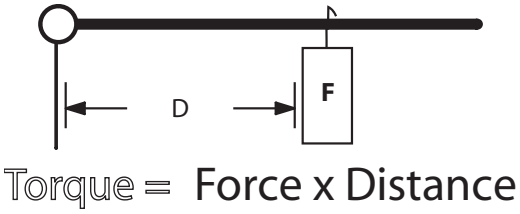
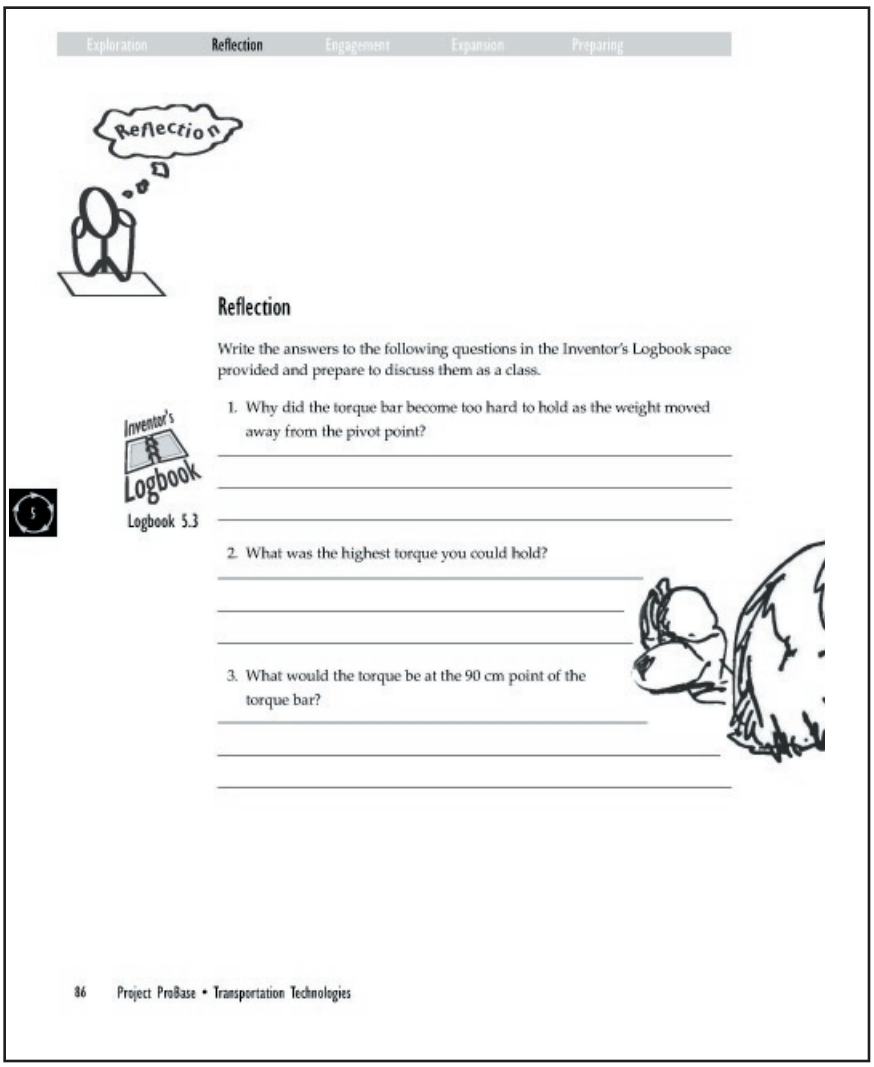


Figure 2. Measuring torque
Note: Drawing is not to scale.

Table 1.
Torque bar trials

Trial	Distance (cm)	Force (g)	Torque (g.cm)
1	0 cm	1000	



Exploration Reflection Engagement Expansion Preparing

Reflection

Reflection

Write the answers to the following questions in the Inventor's Logbook space provided and prepare to discuss them as a class.

Inventor's Logbook

Logbook 5.3

1. Why did the torque bar become too hard to hold as the weight moved away from the pivot point?

2. What was the highest torque you could hold?

3. What would the torque be at the 90 cm point of the torque bar?

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Reflection

Students are asked to write the answers to the following questions in the Inventor's Logbook spaces provided and be prepared to discuss them as a class.

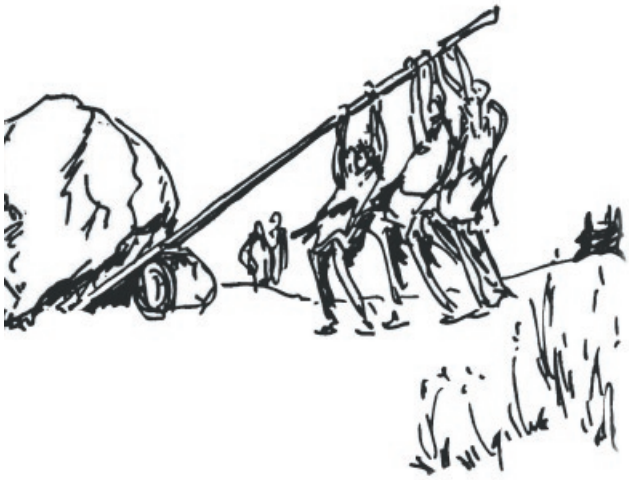
1. Why did the torque bar become too hard to hold up as the weight moved away from the pivot point?
   Because torque increases as the distance increases (T = fd).

2. What was the highest torque you could hold up?
   Student answers will vary.

3. What would the torque be at the 90 cm point of the torque bar?
   90,000 g.cm

4. What would the torque be at 2 meters if you could extend the torque bar?
   200,000 g.cm

4. What would the torque be at 2 meters if you could extend the torque bar?



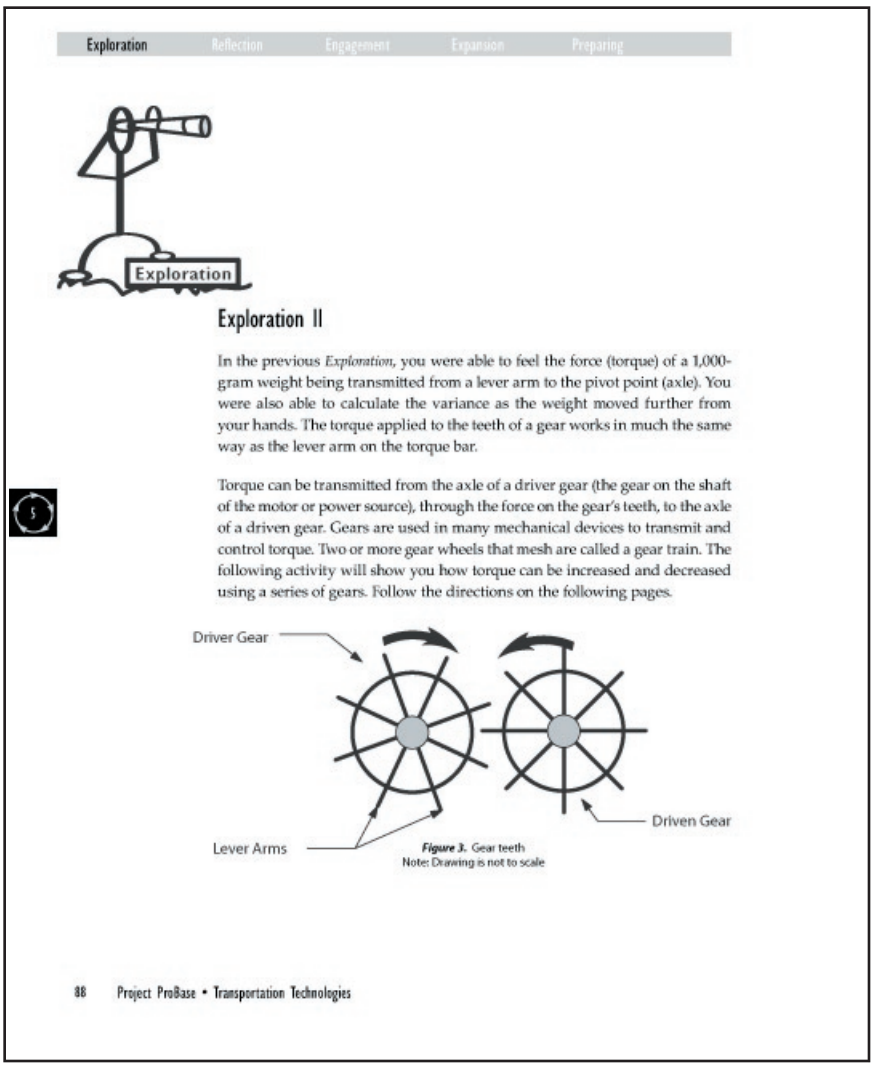
Notes:

Exploration II

In *Exploration II,* students explore torque as it relates to gear trains using a gear box kit.

Teaching Tips

Students are provided directions for assembling several gear trains and for calculating the torque for each arrangement. Assign your students to three-person teams. Remove the directions from the gear box kits and photocopy the front page only. Provide this as reference material for the teams. The directions on the front page will provide the necessary information for them to put the gear box together.



Exploration Reflection Engagement Expansion Preparing

Exploration

Exploration II

In the previous *Exploration,* you were able to feel the force (torque) of a 1,000-gram weight being transmitted from a lever arm to the pivot point (axle). You were also able to calculate the variance as the weight moved further from your hands. The torque applied to the teeth of a gear works in much the same way as the lever arm on the torque bar.

Torque can be transmitted from the axle of a driver gear (the gear on the shaft of the motor or power source), through the force on the gear's teeth, to the axle of a driven gear. Gears are used in many mechanical devices to transmit and control torque. Two or more gear wheels that mesh are called a gear train. The following activity will show you how torque can be increased and decreased using a series of gears. Follow the directions on the following pages.

Figure 3. Gear teeth
Note: Drawing is not to scale

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The motors will not be used until the *Engagement* activity. You may want to put these away in a secure area until they are needed.

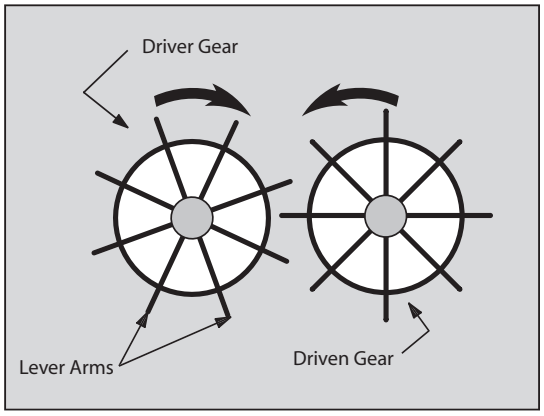
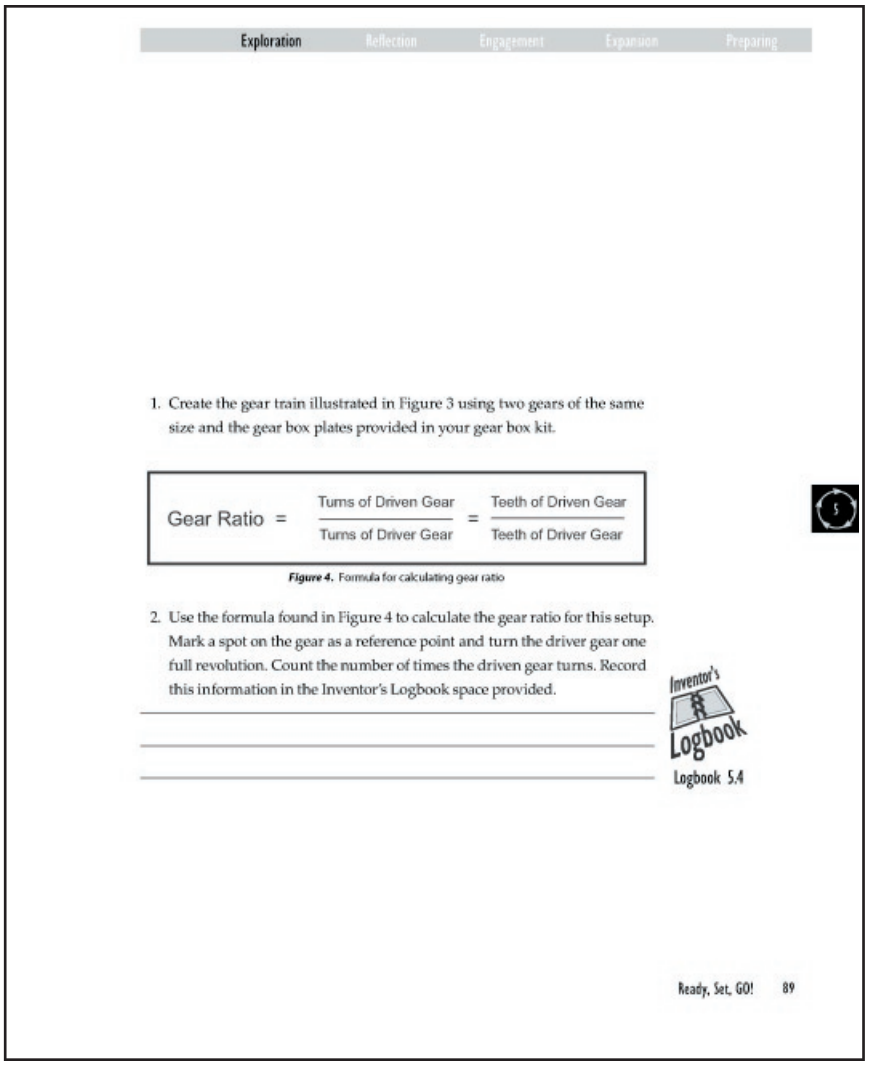


Figure 3. Gear teeth
Note: Drawing is not to scale



Exploration Reflection Engagement Expansion Preparing

1. Create the gear train illustrated in Figure 3 using two gears of the same size and the gear box plates provided in your gear box kit.

$$\text{Gear Ratio} = \frac{\text{Turns of Driven Gear}}{\text{Turns of Driver Gear}} = \frac{\text{Teeth of Driven Gear}}{\text{Teeth of Driver Gear}}$$

Figure 4. Formula for calculating gear ratio

2. Use the formula found in Figure 4 to calculate the gear ratio for this setup. Mark a spot on the gear as a reference point and turn the driver gear one full revolution. Count the number of times the driven gear turns. Record this information in the Inventor's Logbook space provided.

Inventor's Logbook

Logbook 5.4

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Notes:

$$\text{Gear Ratio} = \frac{\text{Turns of Driven Gear}}{\text{Turns of Driver Gear}} = \frac{\text{Teeth of Driven Gear}}{\text{Teeth of Driver Gear}}$$

Figure 4. Formula for calculating gear ratio

Notes:

3. Use one grey gear, one red gear, and gear box plates to set up a similar configuration. Sketch this configuration in the Inventor's Logbook space provided. Calculate the gear ratio and record the ratio in the Inventor's Logbook space provided. Turn the driver gear one full revolution and count the number of times that the driven gear turns. Record this information below.

Inventor's Logbook

Logbook 5.5

The example in Figure 5 has three gears meshed together. Each place where the gears mesh defines a gear ratio. One gear has 10 teeth, one has 50 teeth and one has 30 teeth. This gear train ratio can be calculated in a variety of ways. For example, the formula in Figure 4 can be used to calculate the gear ratio by following these steps:

a. Write a gear ratio fraction that represents each pair of meshing gears

A:B = $\frac{50}{10}$ B:C = $\frac{30}{50}$

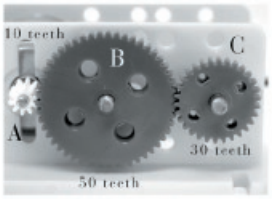
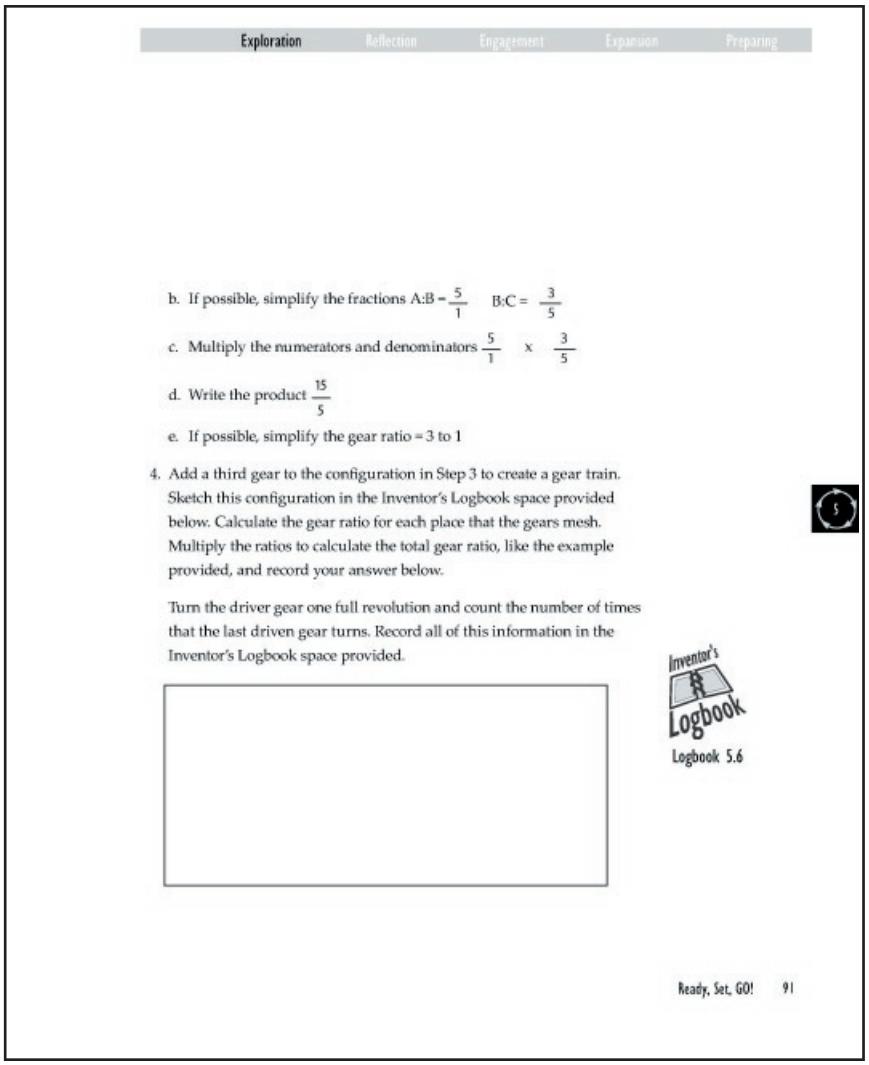


Figure 5. 3-gear configuration



Exploration Reflection Engagement Expansion Preparing

b. If possible, simplify the fractions A:B = $\frac{5}{1}$ B:C = $\frac{3}{5}$

c. Multiply the numerators and denominators $\frac{5}{1}$ x $\frac{3}{5}$

d. Write the product $\frac{15}{5}$

e. If possible, simplify the gear ratio = 3 to 1

4. Add a third gear to the configuration in Step 3 to create a gear train. Sketch this configuration in the Inventor's Logbook space provided below. Calculate the gear ratio for each place that the gears mesh. Multiply the ratios to calculate the total gear ratio, like the example provided, and record your answer below.

Turn the driver gear one full revolution and count the number of times that the last driven gear turns. Record all of this information in the Inventor's Logbook space provided.

Inventor's Logbook

Logbook 5.6

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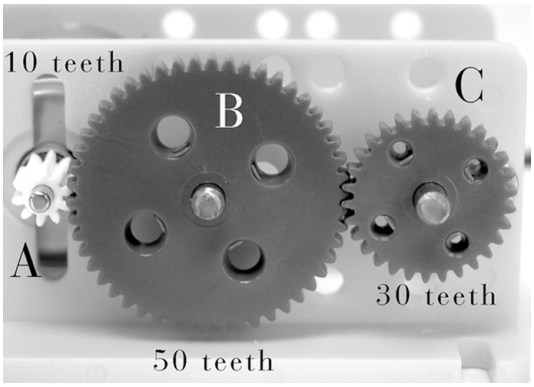


Figure 5. 3-gear configuration

a. Write a gear ratio fraction that represents each pair of meshing gears.

A:B = $\frac{50}{10}$ B:C = $\frac{30}{50}$

b. If possible, simplify the fractions.

A:B = $\frac{5}{1}$ B:C = $\frac{3}{5}$

c. Multiply the numerators and denominators.

$\frac{5}{1}$ x $\frac{3}{5}$

d. Write the product.

$\frac{15}{5}$

e. Simplify if possible.

Gear ratio = 3 to 1

5. Take turns among your team members creating different configurations using at least five gears (make sure that each team member creates at least three different configurations). Have your team members:

   a. Predict the final direction that the last driven gear in the gear chain will rotate and then check to determine accuracy.

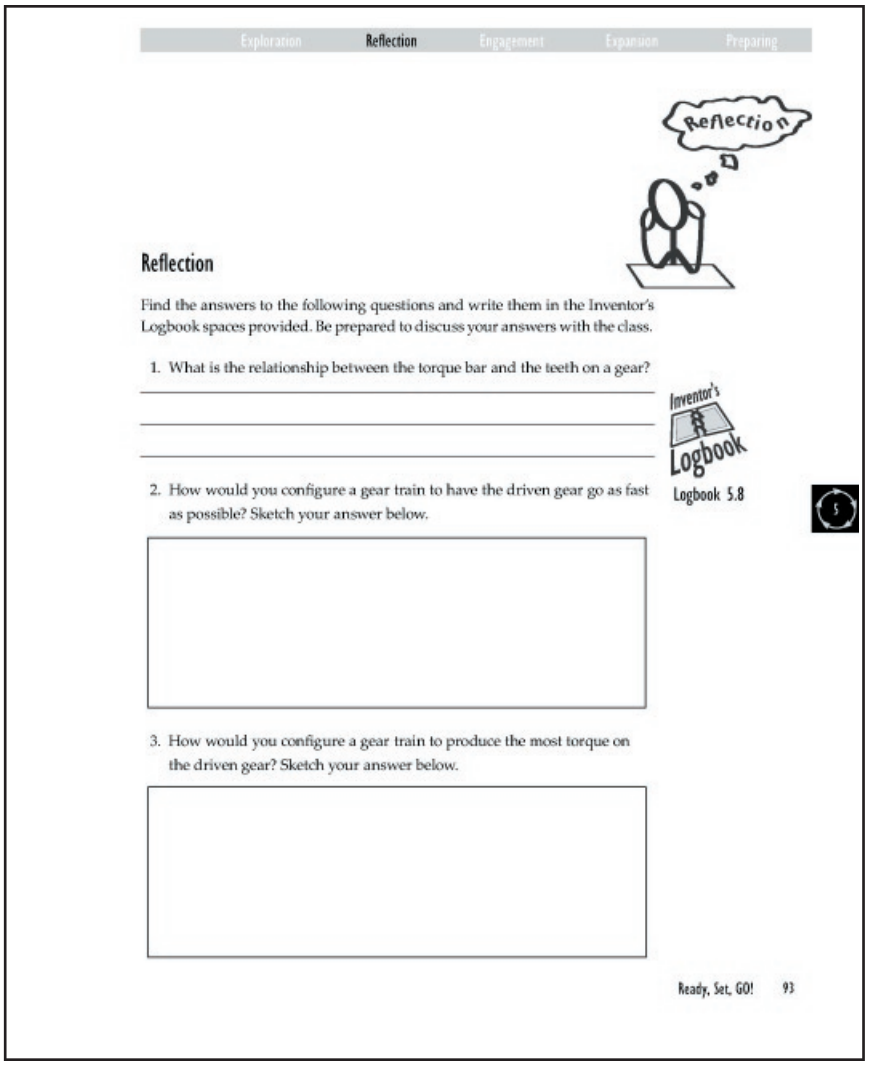
   b. Calculate the total gear ratio for your configuration.

   c. Test predictions by having someone turn the driver gear while observing the last driven gear in the gear chain. How many times did the last driven gear turn for each revolution of the driver gear?

   d. Place your predictions, calculations, and results in the Inventor's Logbook space provided below.

Inventor's Logbook

Logbook 5.7



Exploration Reflection Engagement Expansion Preparing

Reflection

Find the answers to the following questions and write them in the Inventor's Logbook spaces provided. Be prepared to discuss your answers with the class.

1. What is the relationship between the torque bar and the teeth on a gear?

2. How would you configure a gear train to have the driven gear go as fast as possible? Sketch your answer below.

3. How would you configure a gear train to produce the most torque on the driven gear? Sketch your answer below.

Inventor's Logbook

Logbook 5.8

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Reflection

Students are asked to find the answers to the following questions and write them in the Inventor's Logbook spaces provided.

1. What is the relationship between the torque bar and the teeth on a gear?
   Torque is applied to the teeth of a gear much like it is applied to the torque bar.

2. How would you configure a gear train to have the driven gear go as fast as possible?
   Place the big gear on the motor shaft and have it drive a smaller gear. Students are asked to sketch their solutions.

3. How would you configure a gear train to produce the most torque on the driven gear?
   Place the smallest gear on the motor shaft and drive a series of larger gears. Students are asked to sketch their solutions.

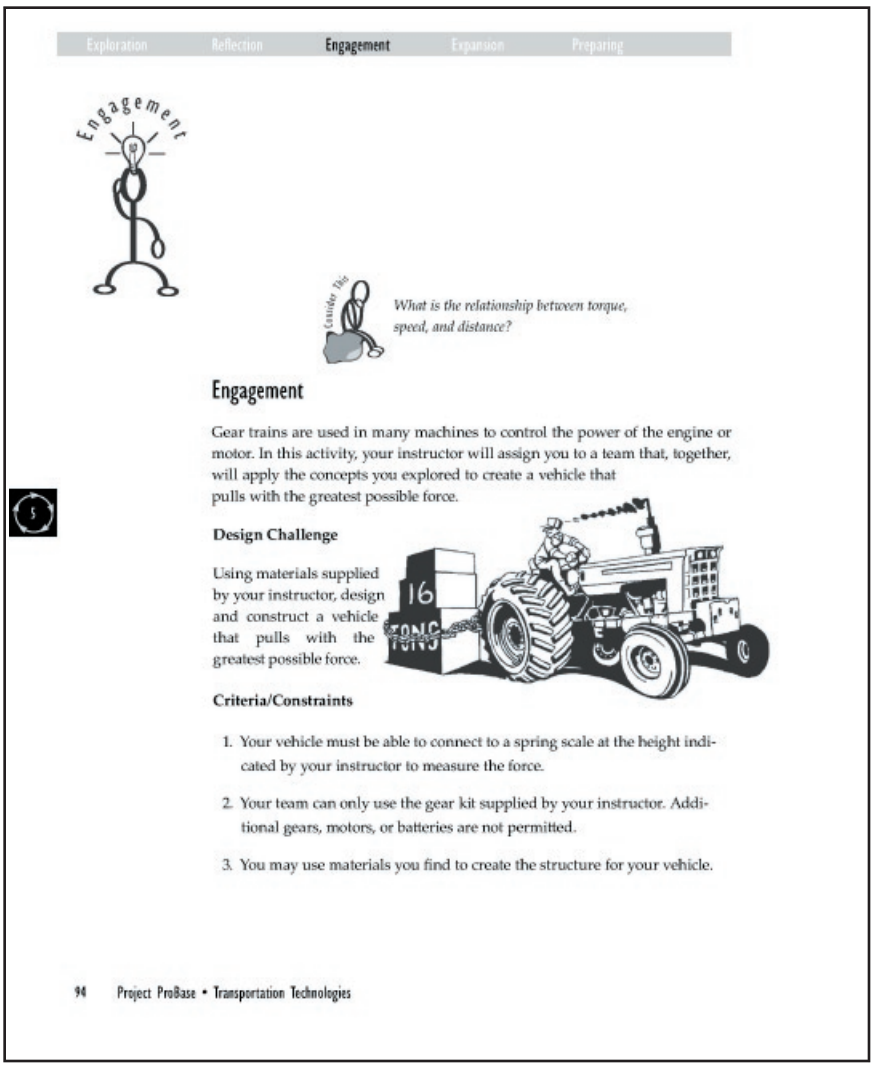
Engagement

The *Engagement* phase of this learning cycle allows students to apply what they have explored about torque and gear trains as they design and construct a vehicle to pull as much force as possible on a spring scale.

Teaching tips

Assign students to teams of three for this design challenge. Students are asked to solve the following design challenge: design and construct a vehicle that pulls the greatest possible force.

Their vehicles must be able to connect to a spring scale at the height that you tell them. You will need to build a small test stand to hold the spring scale. This can be as simple as placing the scale on top of a board clamped to a table. It is important to anchor the spring scale down so that it fairly tests the force pulled by the vehicle.



Exploration Reflection **Engagement** Expansion Preparing

Engagement

Consider This

What is the relationship between torque, speed, and distance?

Engagement

Gear trains are used in many machines to control the power of the engine or motor. In this activity, your instructor will assign you to a team that, together, will apply the concepts you explored to create a vehicle that pulls with the greatest possible force.

Design Challenge

Using materials supplied by your instructor, design and construct a vehicle that pulls with the greatest possible force.

Criteria/Constraints

1. Your vehicle must be able to connect to a spring scale at the height indicated by your instructor to measure the force.
2. Your team can only use the gear kit supplied by your instructor. Additional gears, motors, or batteries are not permitted.
3. You may use materials you find to create the structure for your vehicle.

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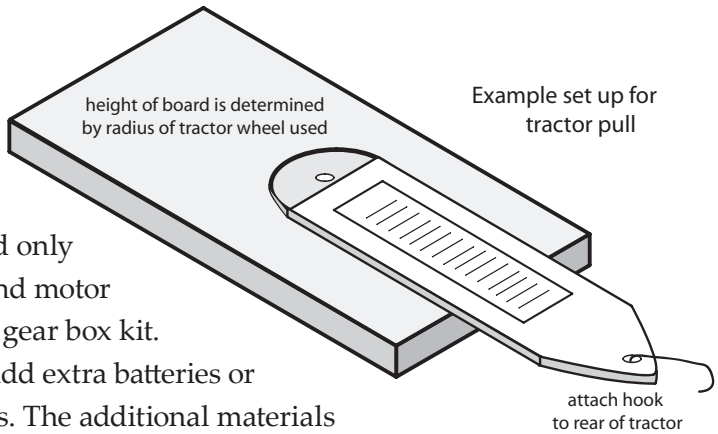
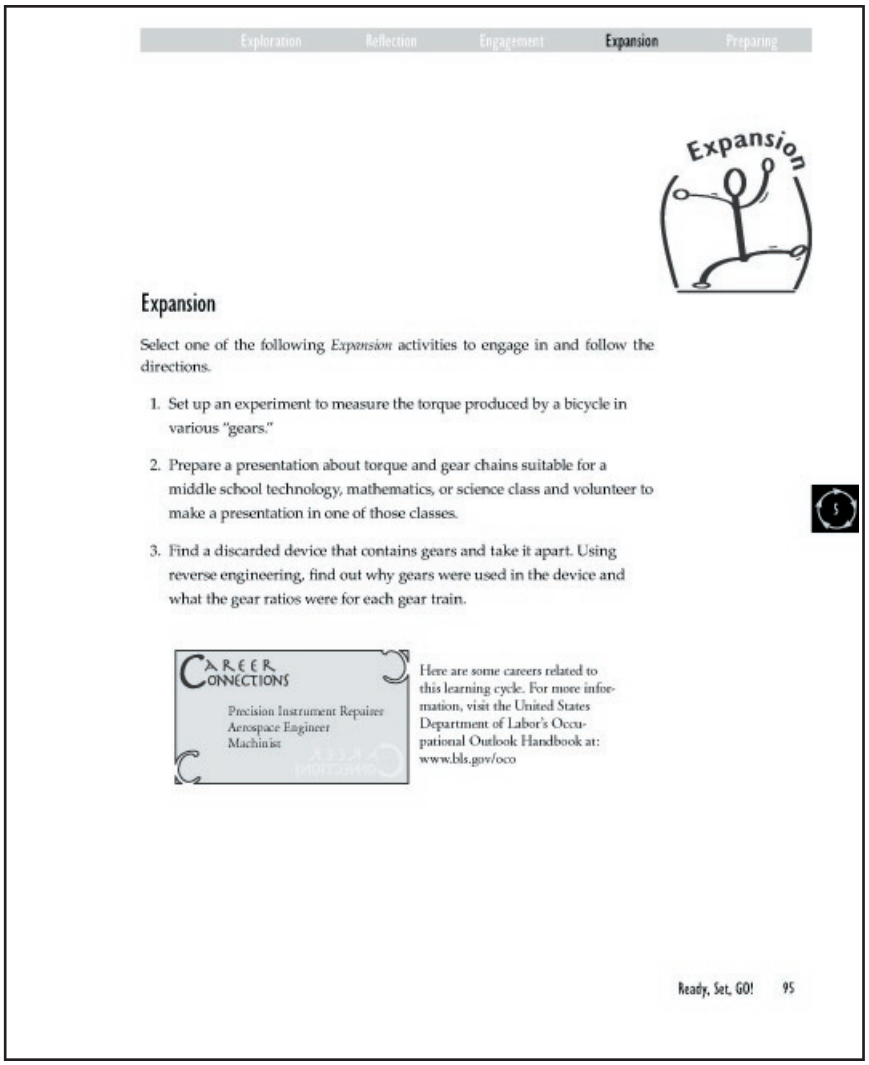


Teaching tips

You may want to simulate a tractor pull competition to find out which team constructed the most powerful vehicle.

Students should only use the gears and motor supplied in the gear box kit. They may not add extra batteries or additional gears. The additional materials needed for the vehicle construction will vary by team. Students should sketch, draw, or use appropriate computer applications to design solutions and prepare a list of required material. Designs and materials lists should be checked before teams begin construction.



Exploration Reflection Engagement Expansion Preparing

Expansion

Expansion

Select one of the following *Expansion* activities to engage in and follow the directions.

1. Set up an experiment to measure the torque produced by a bicycle in various "gears."
2. Prepare a presentation about torque and gear chains suitable for a middle school technology, mathematics, or science class and volunteer to make a presentation in one of those classes.
3. Find a discarded device that contains gears and take it apart. Using reverse engineering, find out why gears were used in the device and what the gear ratios were for each gear train.

CAREER CONNECTIONS

Precision Instrument Repairer
Aerospace Engineer
Machinist

Here are some careers related to this learning cycle. For more information, visit the United States Department of Labor's Occupational Outlook Handbook at: www.bls.gov/oco

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3. Find a discarded device that contains gears and take it apart. Using reverse engineering, find out why gears were used in the device and what the gear ratios were for each gear train.

Expansion

Although not required, these *Expansion* activities are designed to cause teams to delve deeper into the concepts explored in this learning cycle.

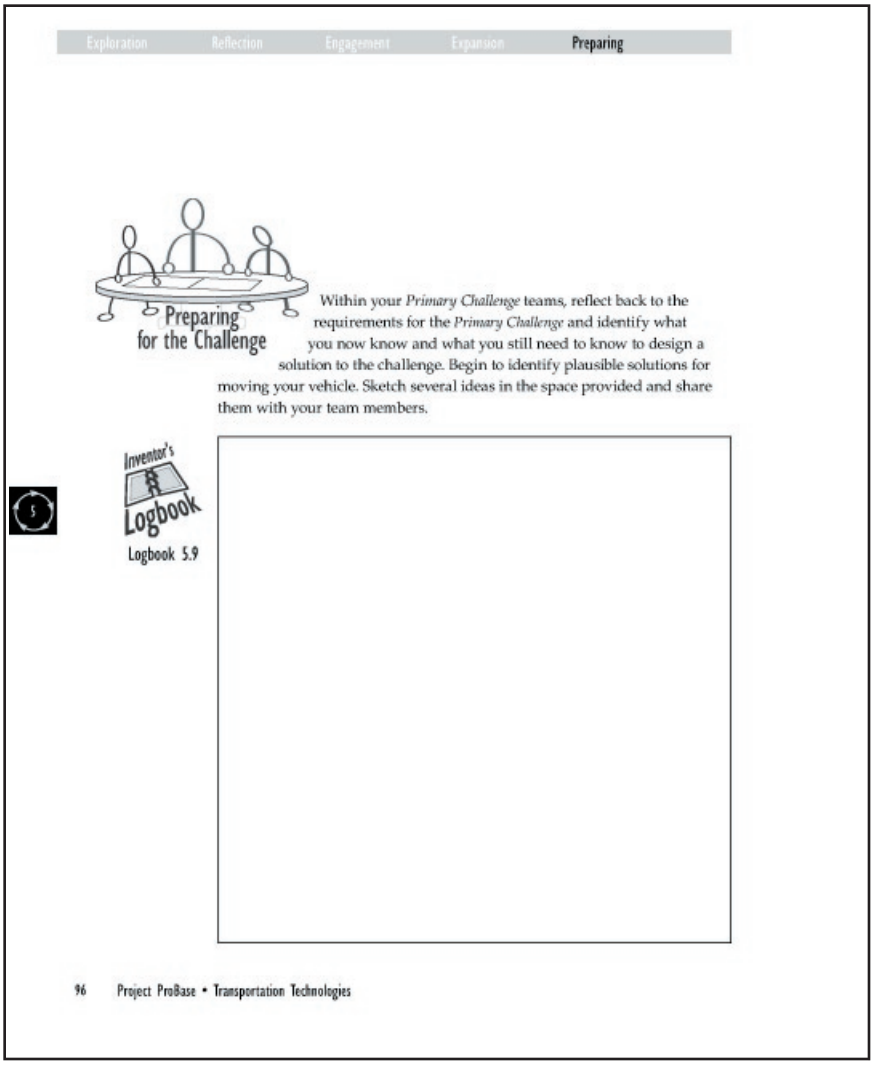
1. Set up an experiment to measure the torque produced by a bicycle in various "gears."
2. Prepare a presentation about torque and gear trains suitable for a middle school technology, mathematics, or science class and volunteer to make a presentation in one of those classes.

Preparing for the Challenge

Students are asked to reflect on the requirements of the *Primary Challenge* and identify what questions they now have answers to, and what questions have yet to be answered to solve the *Primary Challenge.* Allow some time for the students to get into their assigned *Primary Challenge* teams and brainstorm possible power sources for their solutions.

Student Assessment

An assessment rubric has been developed for the *Exploration* and *Engagement* activities. Feel free to change this rubric to better suit your needs.



Exploration Reflection Engagement Expansion **Preparing**

Preparing for the Challenge

Within your *Primary Challenge* teams, reflect back to the requirements for the *Primary Challenge* and identify what you now know and what you still need to know to design a solution to the challenge. Begin to identify plausible solutions for moving your vehicle. Sketch several ideas in the space provided and share them with your team members.

Inventor's Logbook

Logbook 5.9

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Name: Date:

Element	Criteria				Points
	4	3	2	1	
Design work for Engagement	Exceptional design work to increase vehicle torque.	Above average design work to increase vehicle torque.	Average amount of design work to increase vehicle torque.	Limited design work on vehicle.	
Documentation	Exceptional documentation of design; more than 10 logbook entries/sketches.	Above average documentation of design; 7-9 logbook entries/ sketches.	Average documentation of design; 4-6 logbook entries/ sketches.	Below average documentation of design; 1-3 logbook entries/ sketches.	
Design	Exceptional creativity and innovation in design.	Above average creativity and innovation in design.	Average creativity and innovation in design.	Below average creativity and innovation in design.	
Exploration Torque	Fully identifies and comprehends the concept of torque.	Identifies and comprehends most of the concept of torque.	Identifies and comprehends some of the concept of torque.	Does not identify or comprehend the concept of torque.	
Gear Ratio	Fully identifies and comprehends gear ratios.	Identifies and comprehends most gear ratios.	Identifies and comprehends some gear ratios.	Does not identify or comprehend gear ratios.	
				Total Points	