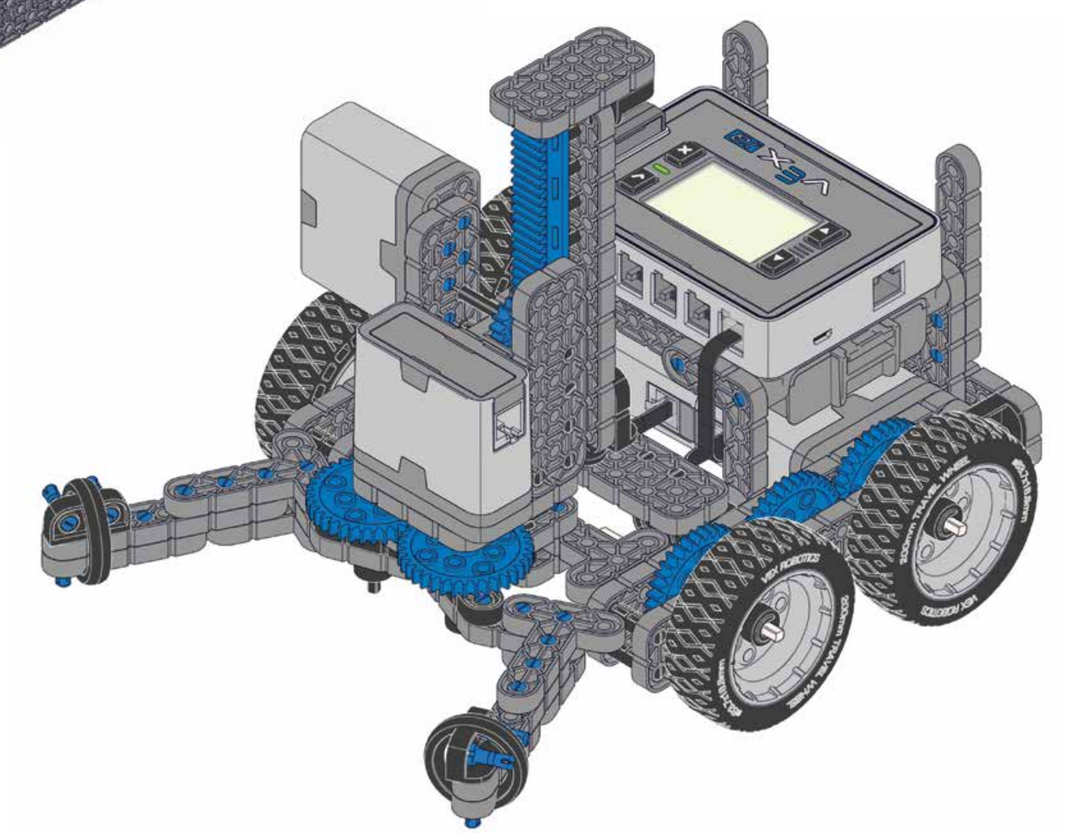
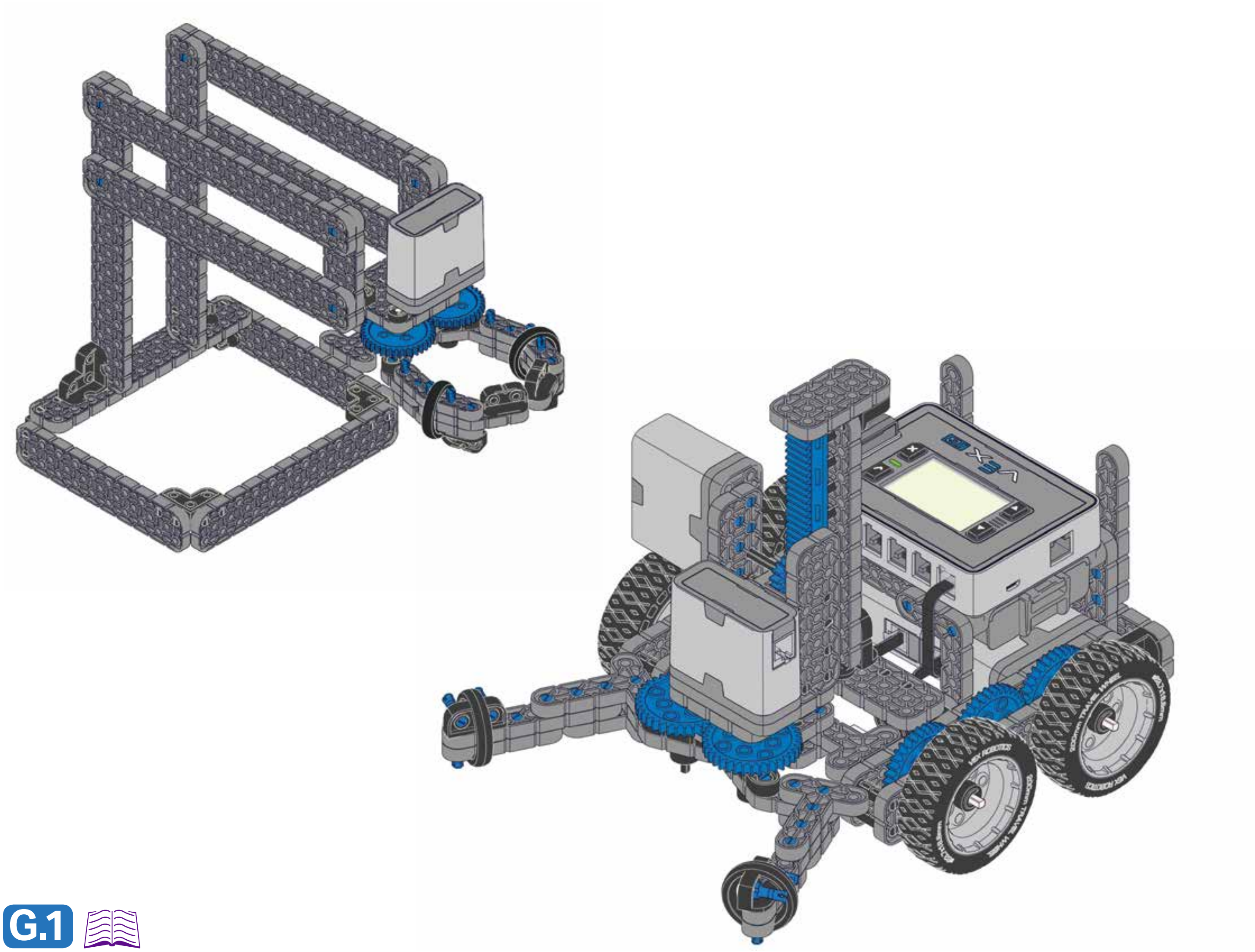
G
Mechanisms





G.1

Mechanisms

Unit Overview:

This unit builds on your knowledge from the Key Concepts unit by digging deeper into certain mechanical aspects of robotics systems. These new elements will lead to higher levels of engineering process and improved designs.

Unit Content:

- DC Motors
- Gear Ratio
- Drivetrains
- Object Manipulation
- Lifting Mechanisms

Unit Activities:

- Matching Exercise
- Gear Ratio Exercises using the Gear Ratio Simulator

Note: Separate copies and/or printouts of activities may be used for student work. Please see your teacher BEFORE writing in this guide. Visit www.vexiq.com/curriculum to download and print PDFs of all exercises!

G.2

Mechanisms: DC Motors (Grades 4-8)

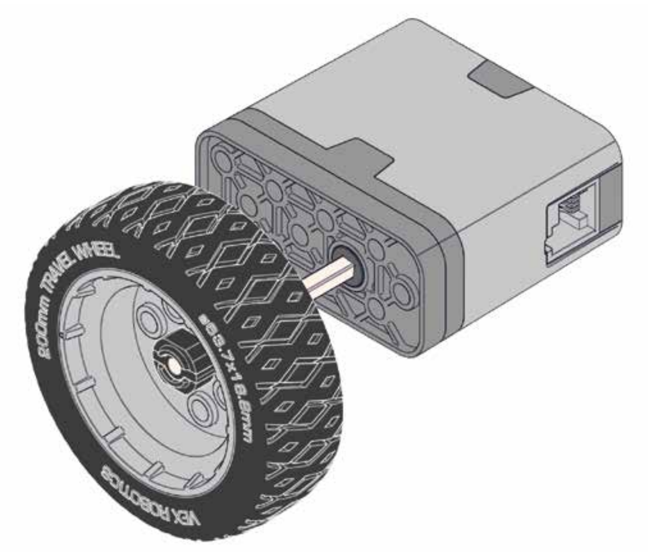
Actuators are used to act upon an environment, usually for moving or controlling a mechanism or system. Actuators drive everything that moves on a mobile robot. The most common type of actuator is a motor; in particular, VEX IQ utilizes **Direct Current (DC) Motors**.

DC Motors convert electrical energy into mechanical energy through the use of electromagnetic fields and rotating wire coils. When a voltage is applied to a motor, it outputs a fixed amount of mechanical power (usually to a shaft, gear, and/or wheel), spinning at some speed with some amount of torque.

Motor Loading

Motors apply torque in response to loading. **Motor Loading** happens when there is any opposing force (such as friction or a heavy mass) acting as a load and requiring the motor to output torque to overcome it. The higher the load placed on a motor output, the more the motor will "fight back" with an opposing torque. However, as you learned in the Key Concepts Unit, since the motor outputs a fixed amount of power, the more torque the motor outputs, the slower its rotational speed.

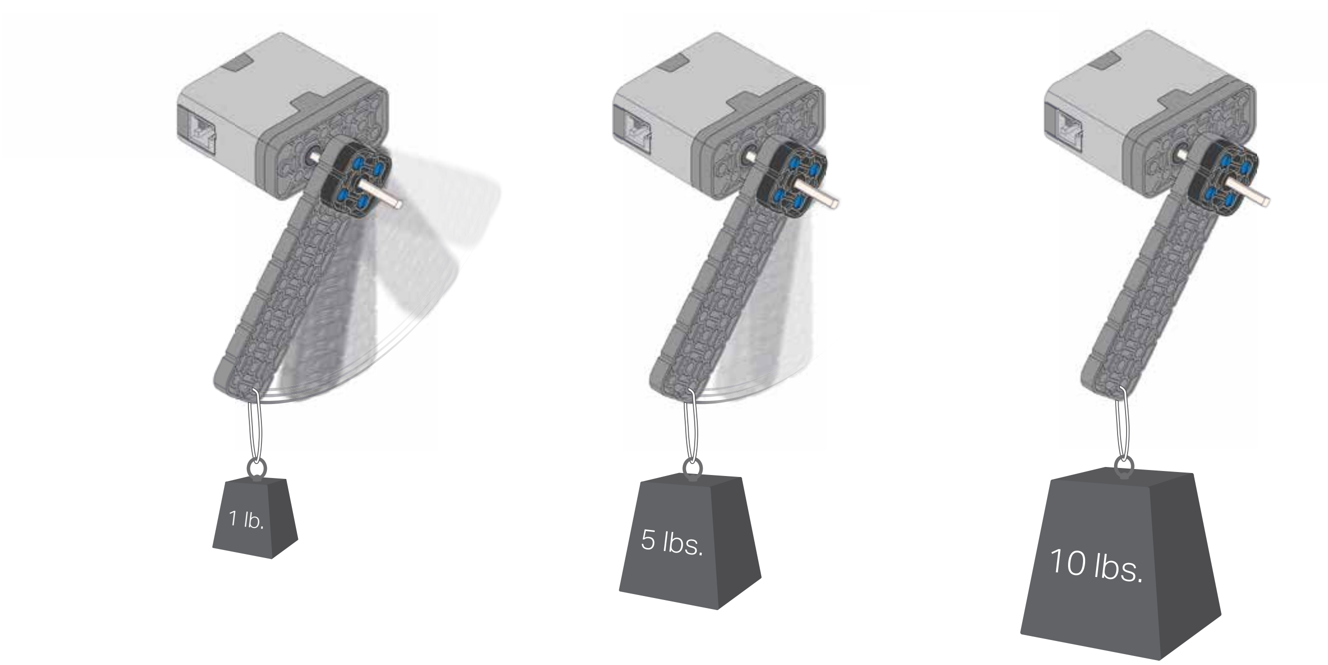
If you keep increasing the load on a motor it eventually stops spinning or **stalls**.



Motor applies torque to overcome friction of a wheel turning against the ground.

Current Draw

A DC Motor draws a certain amount of electrical current (measured in amps) depending on how much load is placed on it. As the load increases on the motor, the more torque the motor outputs to overcome it and the more current the motor draws.



G.3

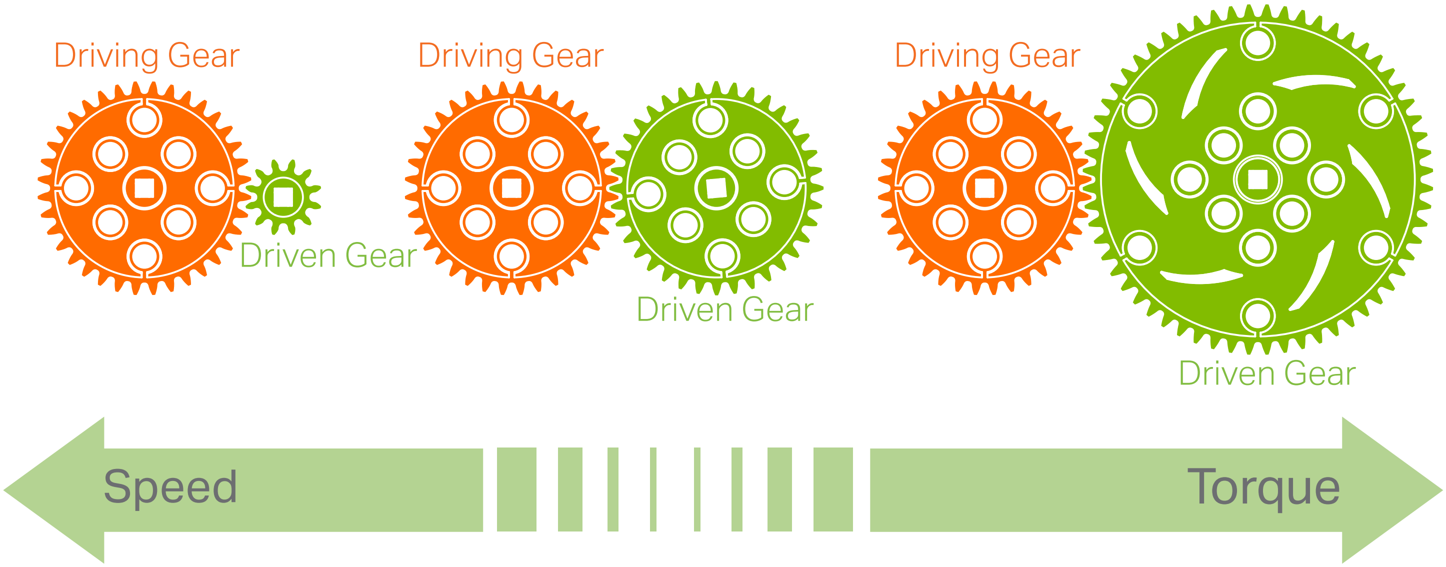
Mechanisms: Gear Ratio

Gear Ratio Basics (Grades 2-8)

As you learned in other lessons, making a **Gear Ratio** change is one of the easiest ways to change Mechanical Advantage in a mechanism or system to achieve desired speed and/or torque. **Gear Ratio** expresses the relationship between a **Driving Gear** (the gear connected to the input power source, such as a motor) and a **Driven Gear** (the gear connected to the output, such as a wheel or mechanism) in a system.

When you have a system with a Driving Gear that is SMALLER than the Driven Gear you will increase Torque and decrease Speed:

Making this kind of change to Mechanical Advantage is helpful when you are trying to move slower mechanically, lift heavier objects, and/or have more pushing ability.



When you have a system with a Driving Gear that is LARGER than the Driven Gear you will increase Speed and decrease Torque:

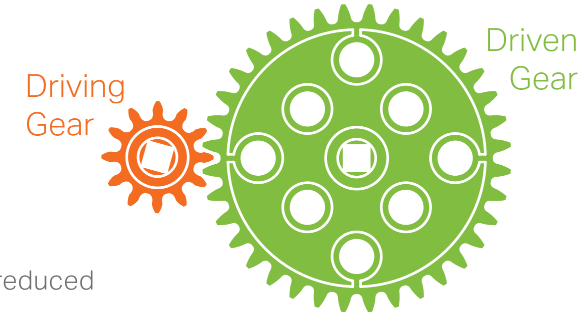
Making this kind of change to Mechanical Advantage is helpful when you are trying to lift or move faster mechanically, you don't require the ability to lift heavy objects, and/or you favor agility over pushing ability in a drivetrain.

G.3 cont.

Expressing Gear Ratio and Gear Reduction (Grades 4-8)

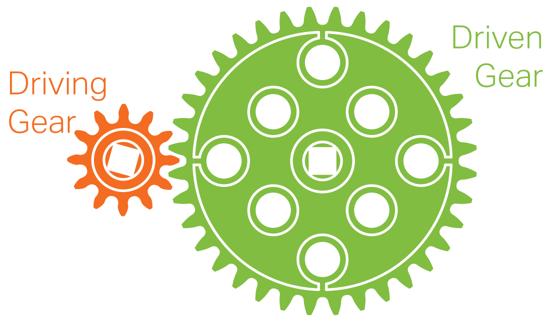
Both **Gear Ratio** and **Gear Reduction** are mathematical expressions that describe the relationship between a **Driving Gear** and a **Driven Gear**. However, it's important to understand the different but similar ways they are expressed. Both use the number of teeth on each gear as key values, although their order is reversed.

Gear Ratio is expressed this way:
(Driving Gear Teeth) : (Driven Gear Teeth)
Gear Reduction is expressed in reverse:
(Driven Gear Teeth) / (Driving Gear Teeth)



Note: Gear Reduction is seen as a fraction that is often reduced to simplify the expression Driven Gear.

Example 1



Gear Ratio 12 : 36

Gear Reduction 36 / 12

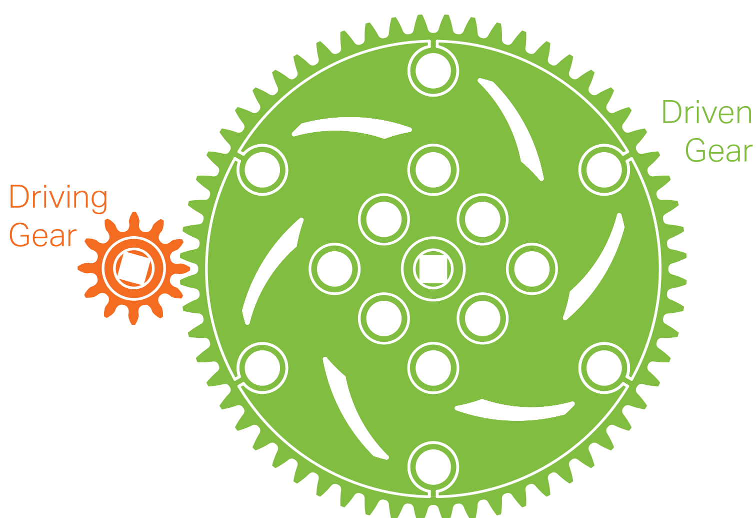
↓

3 / 1

Say "12 to 36 Gear Ratio"

Say "3 to 1 Gear Reduction"

Example 2



Gear Ratio 12 : 60

Gear Reduction 60 / 12

↓

5 / 1

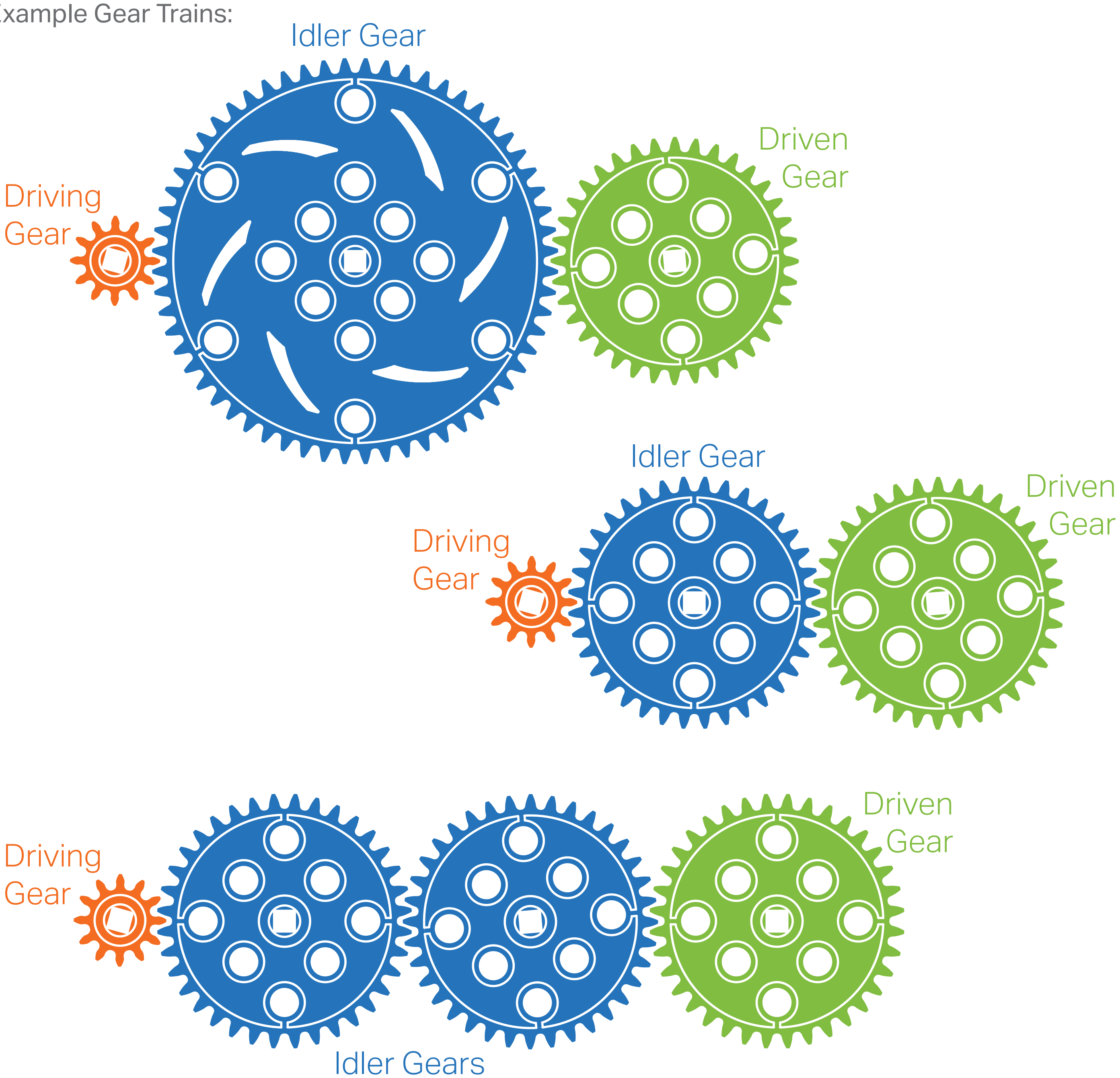
Say "12 to 60 Gear Ratio"

Say "5 to 1 Gear Reduction"

Gear Trains and Idler Gears (Grades 4-8)

A simple **Gear Train** is a connected set of rotating gears that transmits power from an input (like a Driving Gear connected to a motor) to an output (like a Driven Gear connected to a wheel or mechanism). Simple Gear Trains can have any number of gears in a single row. All gears in between the Driving Gear and the Driven Gear that only transmit power are known as Idler Gears. Idler Gears have NO EFFECT on Gear Ratio or Gear Reduction, regardless of the number of teeth they have.

Example Gear Trains:

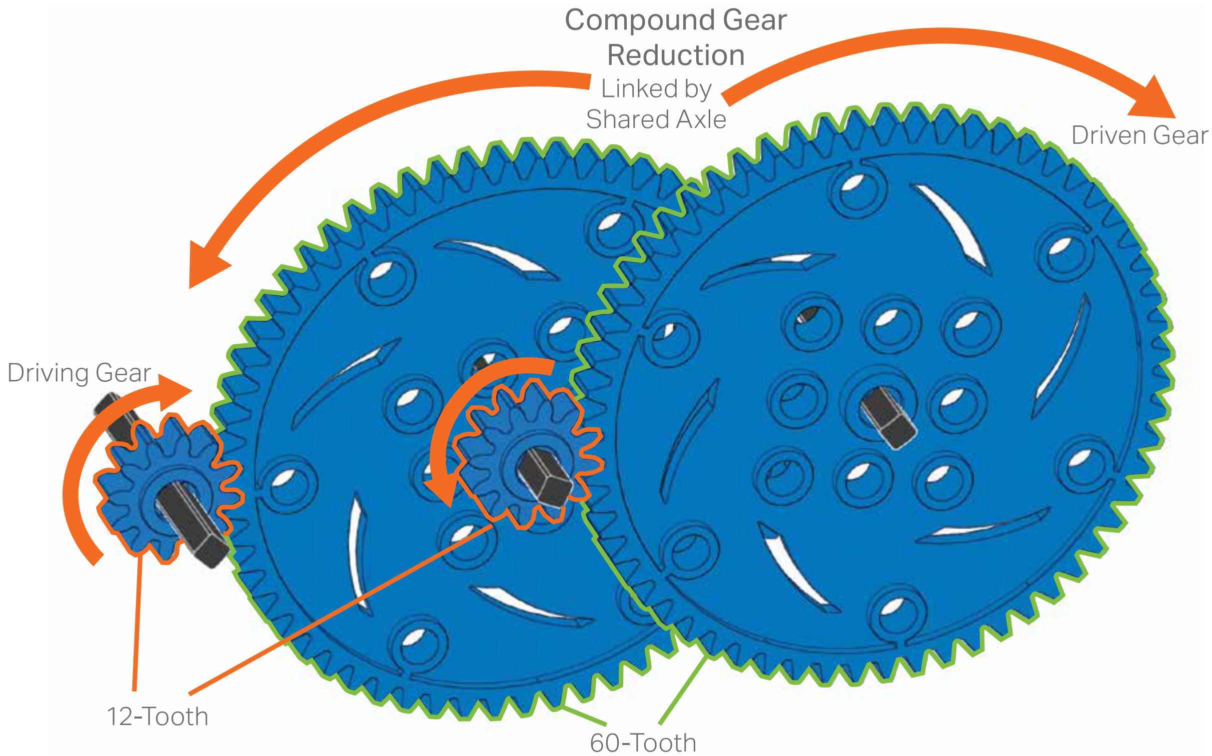


In all three of these example **Gear Trains**, the **Driving Gear** is 12-teeth and the **Driven Gear** is 36-teeth, thus the **Gear Ratio** for all three examples is the exact same - 12:36 . Size and number of **Idler Gears** have no effect on **Gear Ratio** or **Gear Reduction**, they just transmit power!

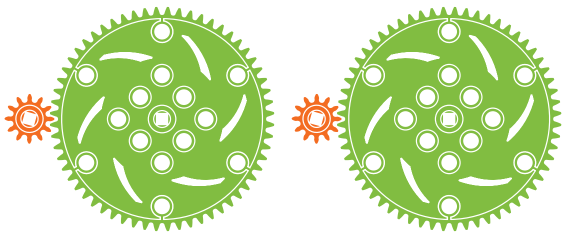
Compound Gears and Compound Gear Reductions (Grades 6-8)

In certain situations, a design may require more mechanical advantage than a single gear ratio can provide or is otherwise impractical. For example, if a VEX IQ robot design requires a 12:500 gear ratio it is a problem because there is no 500-tooth gear available. In this situation, a designer can use multiple gear reductions in the same mechanism. This is called a Compound Gear Reduction.

In a **Compound Gear** system, there are multiple gear pairs. Each pair has its own **Gear Ratio**, and a shared axle connects the pairs to each other. The resulting **Compound Gear** system still has a **Driving Gear** and a **Driven Gear**, and still has a **Gear Reduction**. However, it's now called a **Compound Gear Reduction** and is calculated by multiplying the gear reductions of each of the individual gear pairs.



For the above example with 12-tooth and 60-tooth gears, the overall Gear Reduction is calculated this way:



Gear Reduction

(60 / 12) x (60 / 12)

↓

(5 / 1) x (5 / 1) = 25 / 1

Say "25 to 1 Compound Gear Reduction"

That means the output (**Driven Gear**) shaft is 25 times slower than the input (**Driving Gear**) shaft, and has 25 times as much torque. **Compound Gear Reductions** add up quickly!

Teacher Note: The VEX IQ Gear Ratio Simulator (G.8) and Gear Ratio Exercises (G.9) can be used to help understand this section.

G.4

Mechanisms: Drivetrains (Grades 4-8)

Mobile and Competition robots will vary greatly depending on the tasks they are designed for. However, one thing common among them is that they usually have some method for moving. The robotic subsystem that provides the ability to move is often known as a **Drivetrain**. Drivetrains may come in many different forms – two examples are wheels or treads (like a tank). The wheeled, rolling drivetrain is the most common one found in competition robotics and one of the most popular in the entire industry.

Drivetrain Design

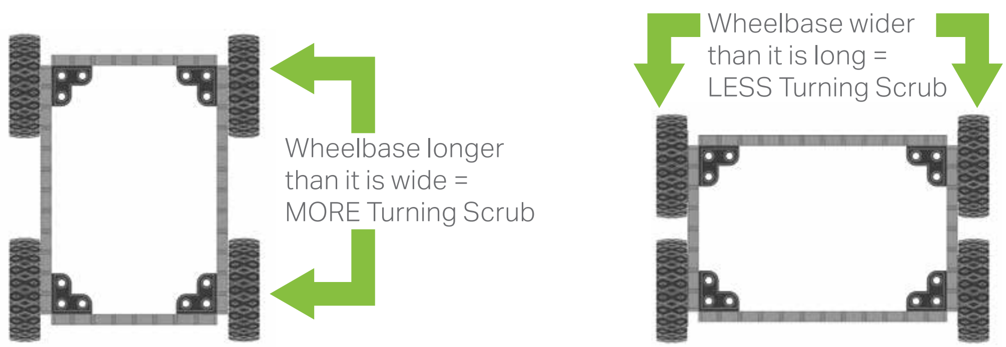
The most basic, multi-functional competition robot **Drivetrain** design consists of:

- A rectangular **Chassis** (the structure of a mobile robot that holds wheels, motors, and/or any other hardware used to make up a **Drivetrain**)
- Two Motors
- Four Wheels
- Gears transmitting Power from the Motors to all Wheels.

The Clawbot IQ Standard Drive Base is one example that you can build. However, **Drivetrains** can come in all shapes and sizes - some don't provide power to all wheels, use different types of wheels, or are not even a rectangular shape! Whatever the details of your **Drivetrain**, you should always be aware of a property known as **Turning Scrub**.

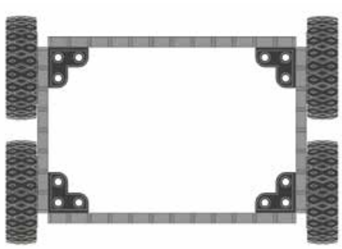
Turning Scrub is the friction that resists turning. This friction is created from the wheels dragging sideways on the ground as a robot (or other mobile vehicle) turns. The greater the **Turning Scrub** in a **Drivetrain**, the harder it is for a robot to turn. **Turning Scrub** in a basic **Drivetrain** can be easily managed and minimized in two ways:

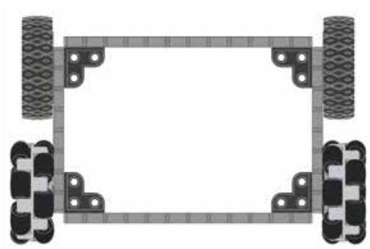
1. Make sure that the **Wheelbase** (distance between **Drivetrain** wheels) is wider (side-to-side) than it is long (front-to-back):



2. Use different wheel and/or tire types to reduce the friction of **Turning Scrub**:

Four regular VEX IQ Tires = MORE Turning Scrub





Two regular VEX IQ Tires + Two VEX IQ Omni-directional Wheels = LESS Turning Scrub

Try building the example **Drivetrains** above to see the **Turning Scrub** effect!

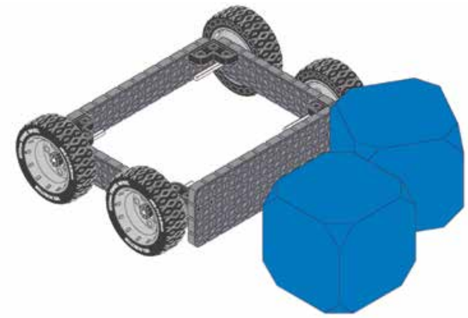
G.5

Mechanisms: Object Manipulation (Grades 4-8)

In mobile and competition robotics, an Object Manipulator is a mechanism that allows a robot to interact with objects in its environment. There are three basic categories of Object Manipulators: Plows, Scoops, and Friction Grabbers.

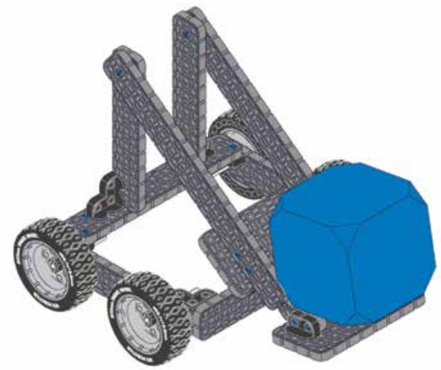
Plows

The first Object Manipulator category applies a single force to the side of an object. Plows move objects without actually picking them up and are by far the easiest manipulator type to design and build.



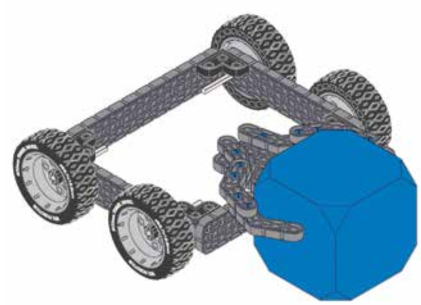
Scoops

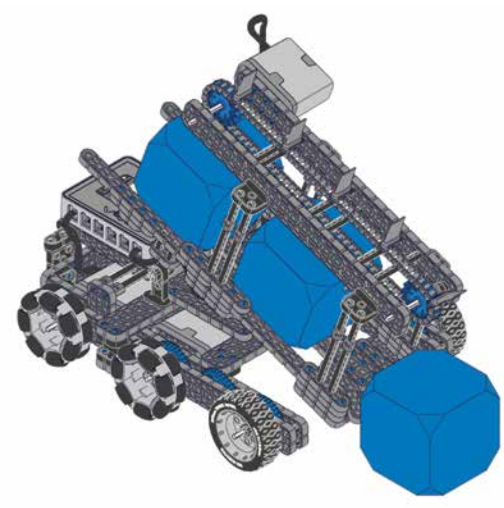
The second Object Manipulator category applies force underneath an object such that the object can be elevated and carried. Once an object is on a Scoop, it can be lifted and lowered relying on gravity to keep the object on or in the Scoop.



Friction Grabbers

The third Object Manipulator category applies a force to an object in at least two places, allowing the object to be pinched or grabbed. Thus, Friction Grabbers have the ability to hold objects securely and are generally the manipulator type that provides the most control over objects. The most common form of this manipulator type is a pinching claw.





Regardless of which category an Object Manipulator fits into, some are designed to handle single objects, while others are designed to collect and hold multiple objects. Any specialized Object Manipulator designed to collect and hold multiple objects at one time is known as an Accumulator. Accumulators, when desired, can allow for greater efficiency of an object manipulation system.

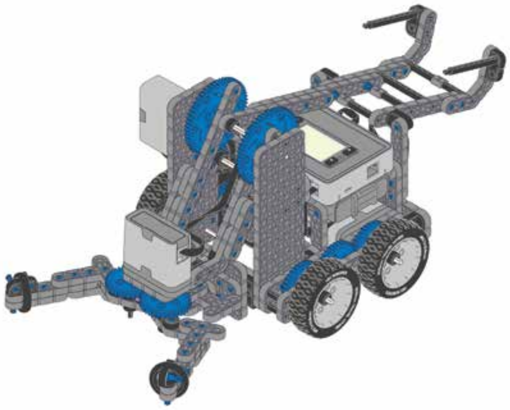
G.6

Mechanisms: Lifting Mechanisms (Grades 4-8)

Before discussing **Lifting Mechanisms**, it's important to know what a **Degree of Freedom** is. A **Degree of Freedom** refers to an object's ability to move in a single independent direction of motion. To be able to move in many directions means something has many **Degrees of Freedom**. Moving up and down is one degree of freedom, moving right and left is another; something that can move up/down and left/right has TWO **Degrees of Freedom**.

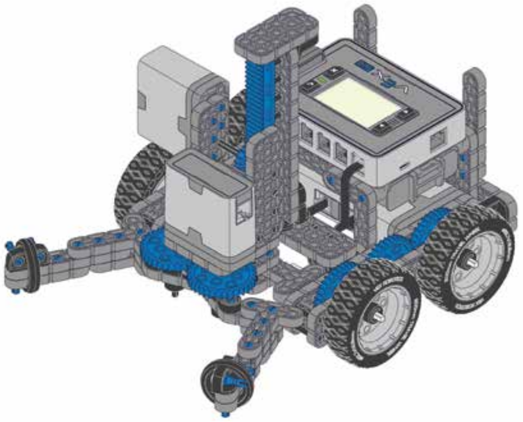
A **Lifting Mechanism** is any mechanism designed to move to perform tasks and/or lift objects. With that understood, let's look at **Lifting Mechanism** types. In competition robotics, there are three basic types of **Lifting Mechanisms**: **Rotating Joints**, **Elevators**, and **Linkages**.

Rotating Joints



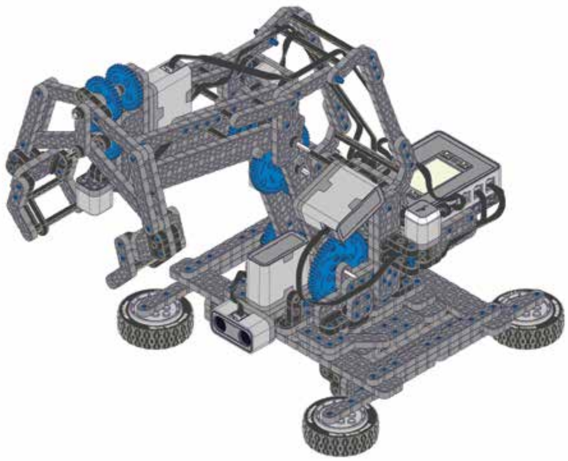
The most frequently used lifting mechanism in mobile and competition robotics is a **Rotating Joint**. **Rotating Joints** are the simplest **Lifting Mechanisms** to design and build. In VEX IQ, using a shaft and gears quickly creates an arm that will rotate and lift. This type of **Lifting Mechanism** moves on an arc, changing both the distance any manipulated objects are from a robot base, and changing the orientation of those objects (relative to their environment) on the way up.

Elevators



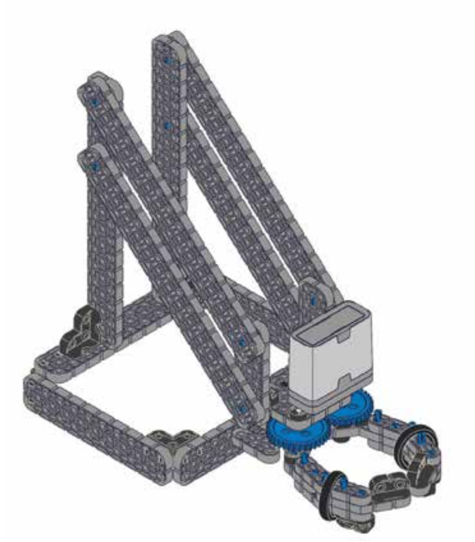
Another lifting mechanism used in mobile and competition robotics is an **Elevator**. While not as common as the **Rotating Joint**, the **Elevator** uses linear (straight line) motion to lift straight up. In VEX IQ, one way that elevators can be built is with Rack Gears and Linear Sliders, both sold as part of the Gear Kit. This type of **Lifting Mechanism** moves straight up and down, keeping the distance between any manipulated objects and the robot base, as well as the orientation of those objects, consistent on the way up.

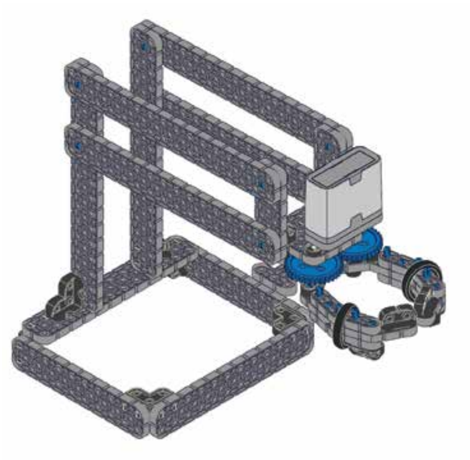
Linkages

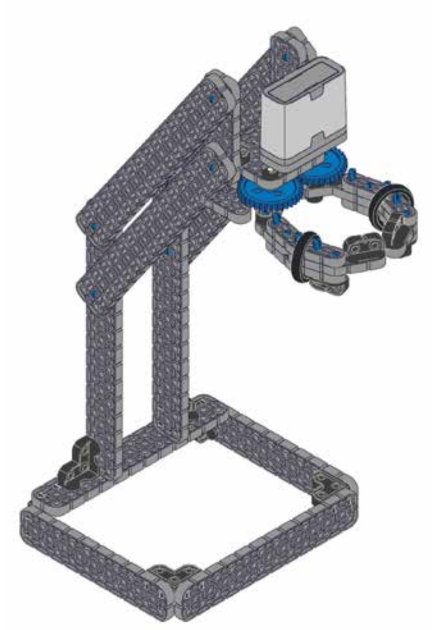


Linkages can also be used to build **Lifting Mechanisms**. Linkages consist of a series of rigid bodies called links, connected together by freely rotating joints. **Linkages** convert an input motion into a different type of output motion and can be very consistent. For example the input motion could be a **Rotating Joint**, but the **Linkage** could produce **Elevator**-like output motion. In VEX IQ, combinations of different-sized beams, shafts, and/or connector pins can be used to construct a **Linkage**.

One of the simplest and most common linkage types is the Four-Bar **Linkage**. This is a linkage system that provides a wide variety of motions depending on its configuration. By varying the length of each link, one can greatly change the output motion. The most basic type of Four-Bar **Linkage** is one where link pairs are equal length and parallel to each other, as seen below:







If you have time, try building the Four-Bar linkage show here to see how a linkage works!

Rotating Joint, Elevator, or Linkage?

Elements to consider when deciding what type of **Lifting Mechanism** is best for your robot's needs:

- Elevation Required – How high do you have to lift?
- Object Orientation – Do the objects you are lifting have to remain in a certain orientation?
- Size Limitations – Are there design or environmental limitations to your robot's size?
- Complexity – How many degrees of freedom are desired? What type of hardware is required?
- Motors Required – Do you have enough? Is the total number limited?

G.7

Mechanisms Matching Exercise

Student Name(s): ____

Teacher/Class: ______________________________ Date: ______________

Instructions:

Match terms from the word bank to the correct definition by writing terms on the correct line. Each term is only used once.

Word Bank:

Accumulator	Chassis	DC Motors
Gear Train	Degree of Freedom	Driven Gear
Driving Gear	Friction Grabbers	Drivetrain Elevator
Gear Ratio	Idler Gears	Lifting Mechanism
Object Manipulator	Linkages	Motor Loading
Plows	Rotating Joint	Scoop
Stalls	Turning Scrub	Wheelbase

From DC Motors (grades 4-8):

________________________ convert electrical energy into mechanical energy through the use of electro-magnetic fields and rotating wire coils.

________________________ happens when there is any opposing force (such as friction or a heavy mass) acting as a load and requiring the motor to output torque to overcome it.

If you keep increasing the load on a motor it will eventually stops spinning or ______________.

From Gear Ratio (grades 2-8):

________________________ expresses the relationship between a Driving Gear and a Driven Gear in a system.

A ______________________ is the gear connected to the input power source, such as a motor.

A ______________________ is the gear connected to the output, such as a wheel or mechanism in a system.

A simple ______________________ is a connected set of rotating gears that transmits power from an input to an output. All gears in between the Driving Gear and the Driven Gear that only transmit power are known as ______________________.

From Drivetrains (grades 4-8):

The robotic subsystem that provides the ability to move is often known as a ______________ ____________.

A ______________________ is the structure of a mobile robot that holds wheels, motors, and/or any other hardware used to make up a Drivetrain.

________________________ is the friction that resists turning.

The ______________________ is the distance between Drivetrain wheels.

G.7 cont.

From Object Manipulation (grades 4-8):

An ______________________________ is a mechanism that allows a robot to interact with objects in its environment.

______________________________ move objects without actually picking them up and they are by far the easiest manipulator type to design and build.

A ______________________________ applies force underneath an object such that the object can be elevated and carried.

______________________________ apply a force to an object in at least two places, allowing the object to be pinched or grabbed.

Any specialized Object Manipulator designed to collect and hold multiple objects at one time is known as an ____________________________.

From Lifting Mechanisms (grades 4-8):

A ______________________________ refers to an object's ability to move in a single independent direction of motion.

A ______________________________ is any mechanism designed to move to perform tasks and/or lift objects.

The most frequently used lifting mechanism in mobile and competition robotics is a ____________ ______________________ .

An ______________________________ uses linear (straight line) motion to lift straight up.

__________________________ convert an input motion into a different type of output motion.

G.8

VEX IQ Gear Ratio Simulator Assembly Instructions

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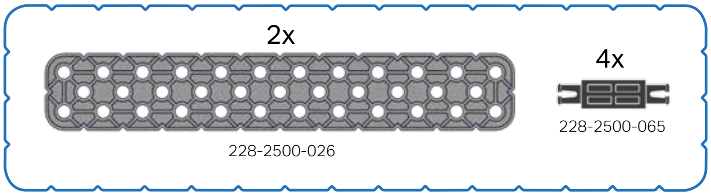

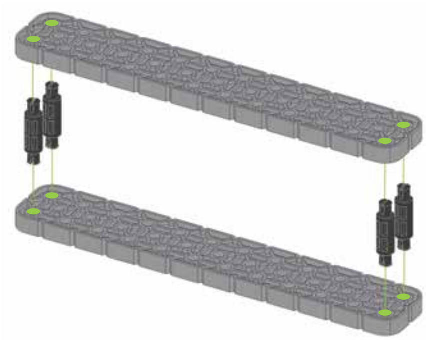

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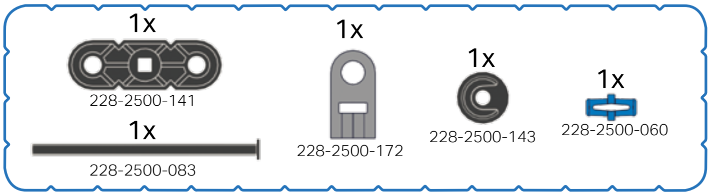

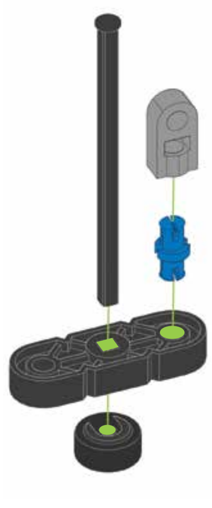

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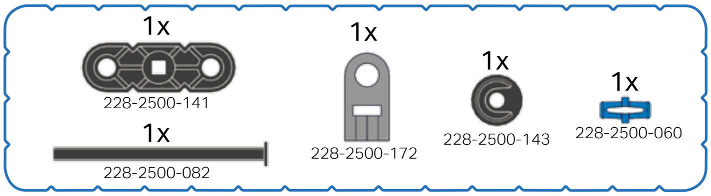

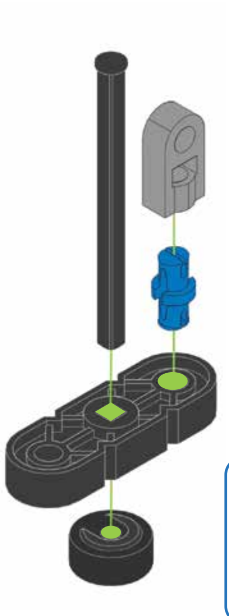

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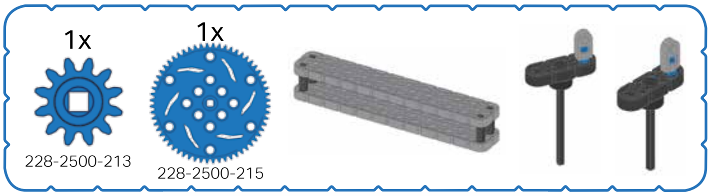
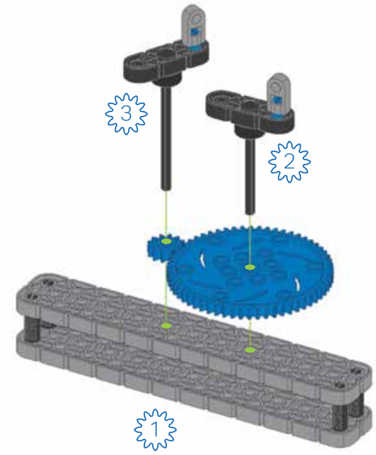
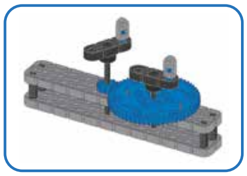
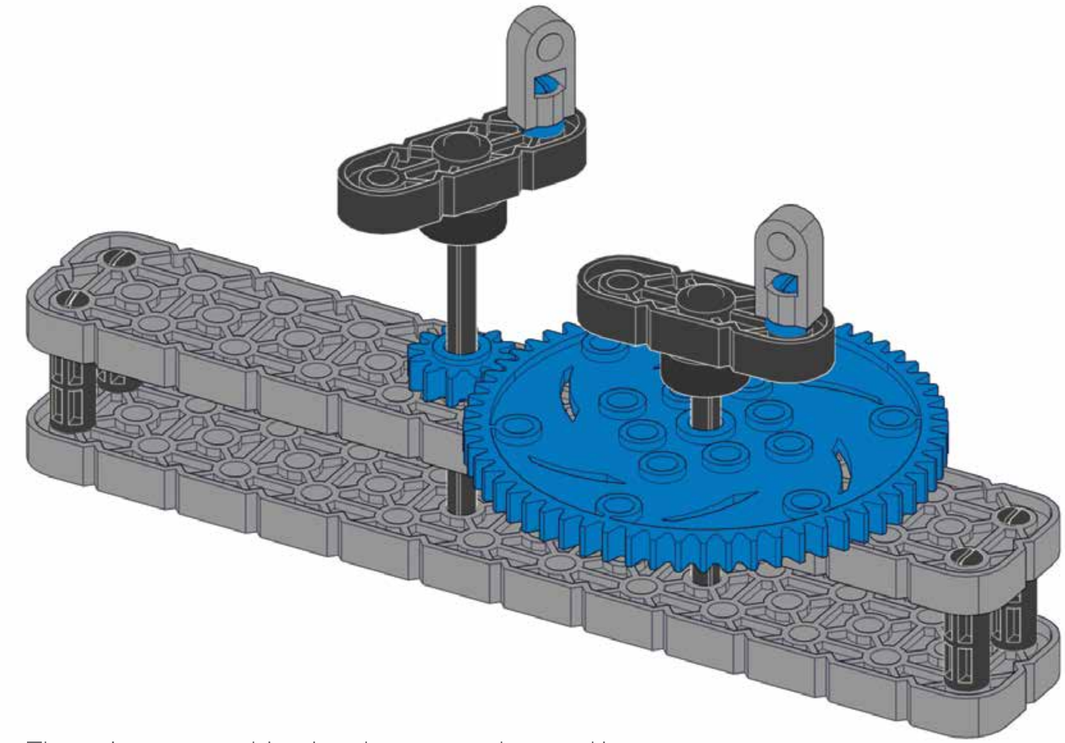






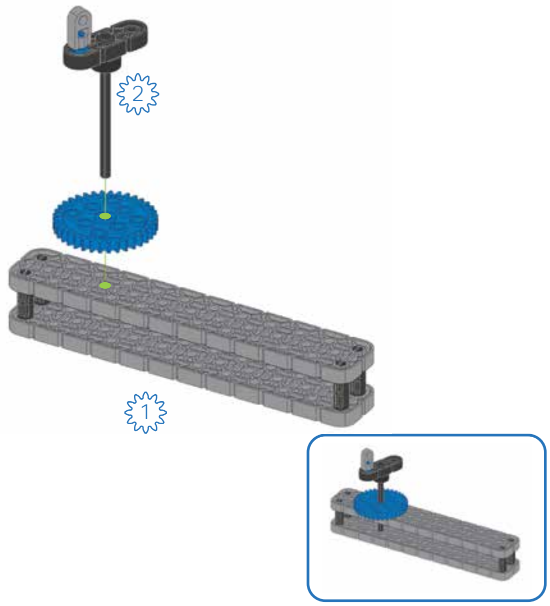
G.8 cont.

Basic Gear Assembly



Note: The only gear combination that cannot be used is a 12-tooth gear on both input and output shafts.

5



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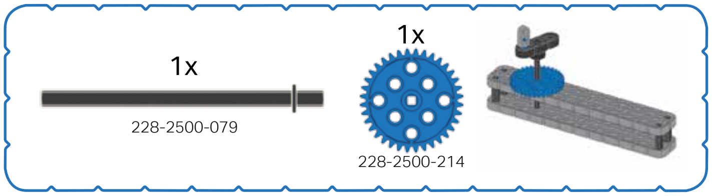

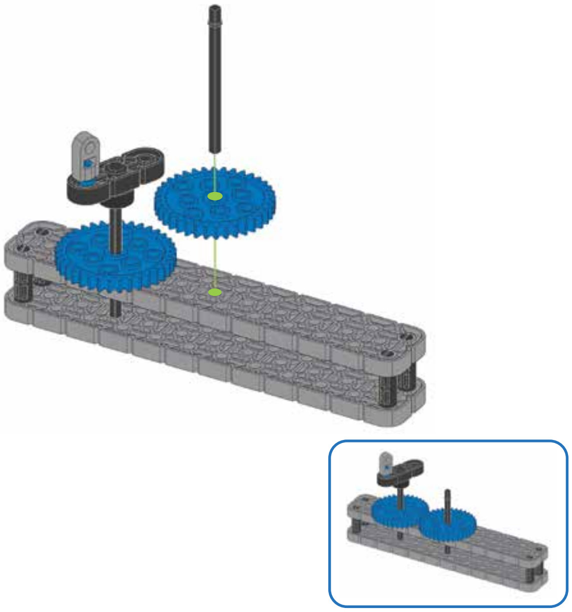

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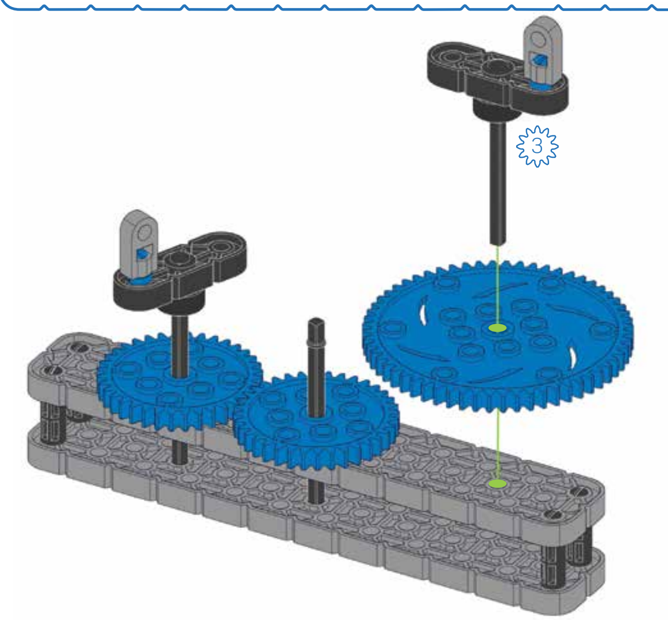
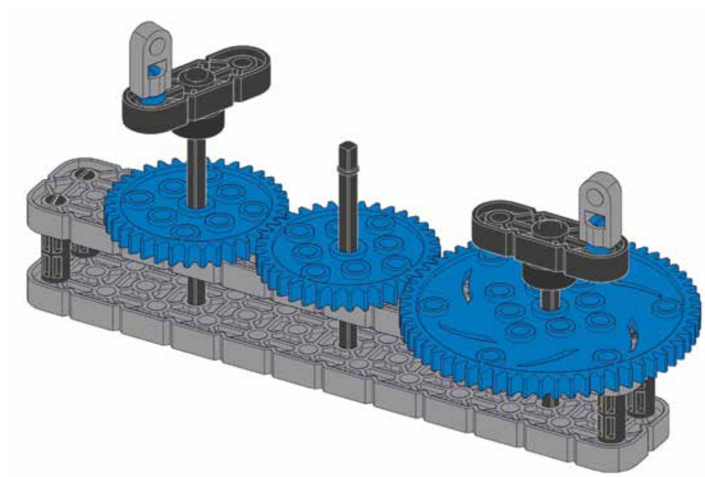
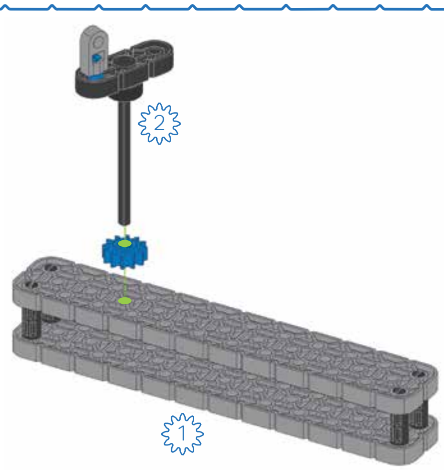


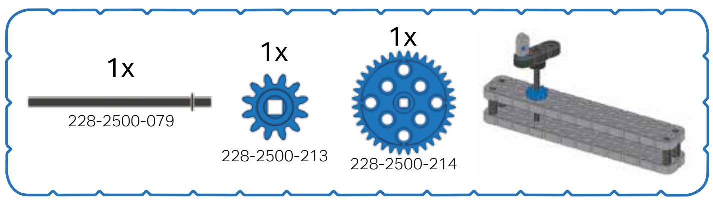
Assembly with Idler Gear

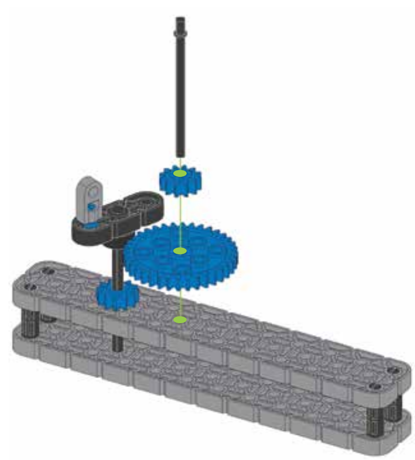


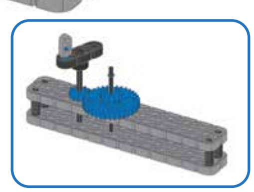
8



9

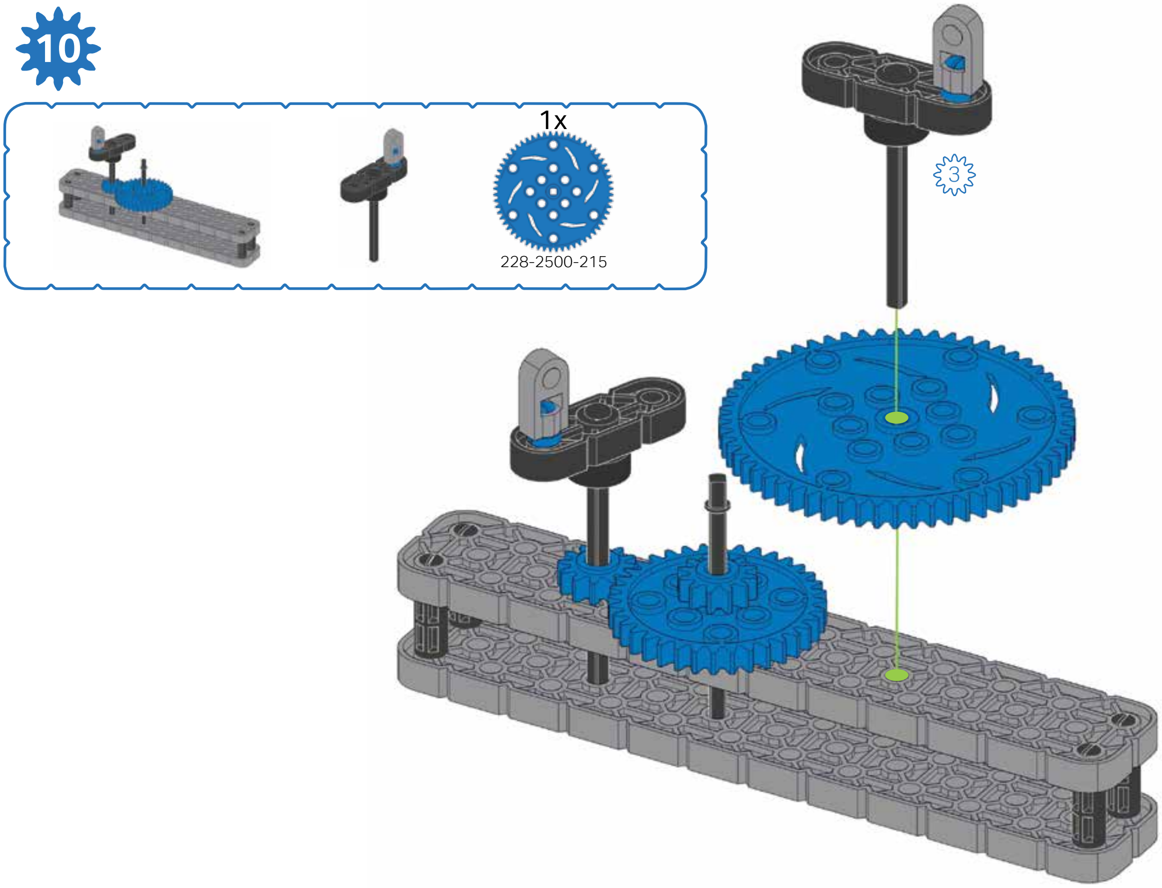




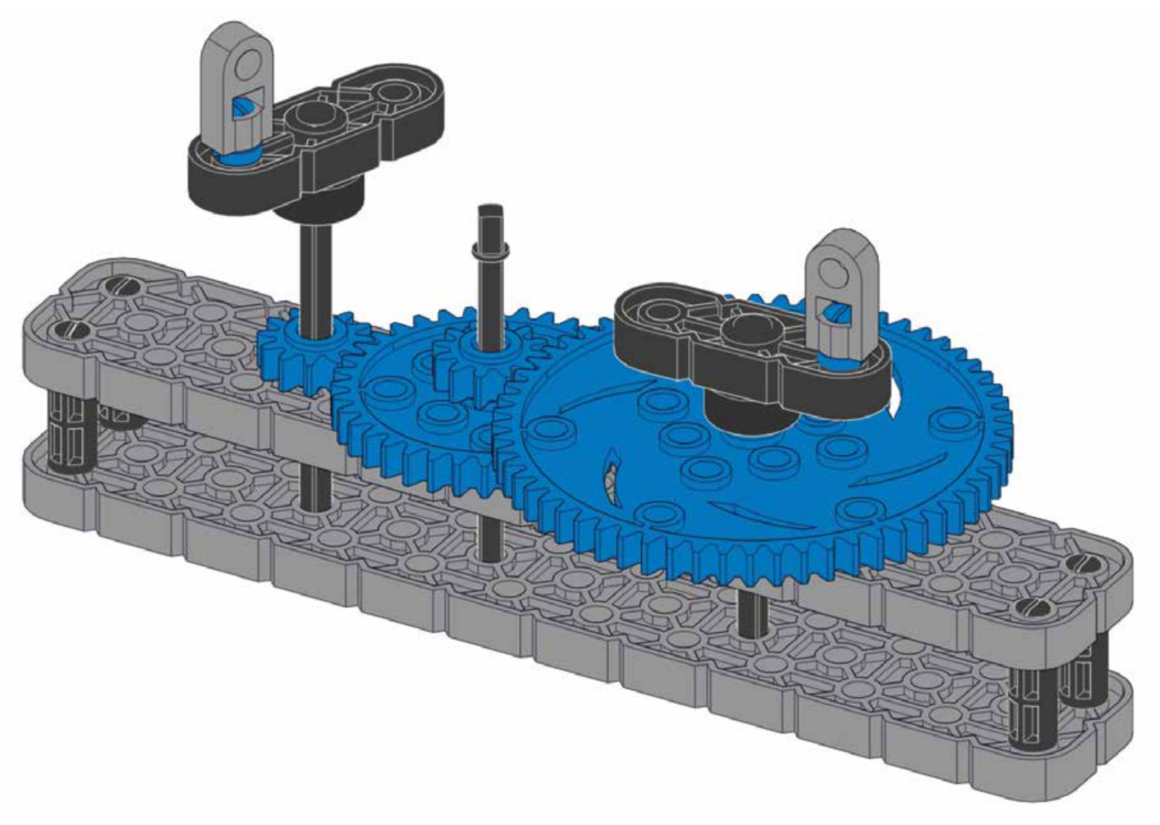


G.8 cont.

10



Assembly with Compound Gear Reduction



G.9

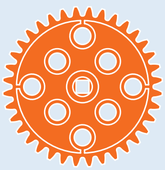
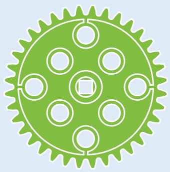
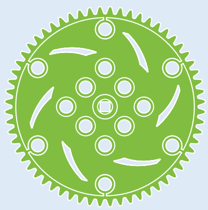
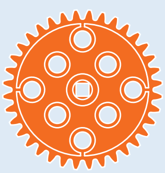
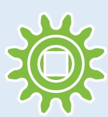
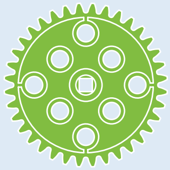
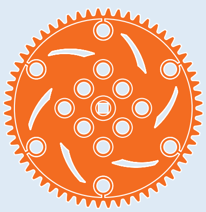
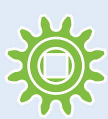
Mechanisms Gear Ratio Exercise #1: Gear Ratio Basics (Grades 2-8)

Student Name(s): ____

Teacher/Class: ______________________________ Date: ______________

Instructions:

After learning about Gear Ratio Basics from section G.3, demonstrate what you have learned by circling correct answers below. You may also build and use the VEX IQ Gear Ratio Simulator along with 12-tooth, 36-tooth, and 60-tooth gears to help find answers.

Driving Gear (Input)	Driven Gear (Output)	What does this ratio create comparing output to input? (Circle the correct answer below)		
36-tooth 	36-tooth 	Equal: Speed ↑ Torque ↑	Torque ↑ Speed ↓	Speed ↑ Torque ↓
12-tooth 	60-tooth 	Equal: Speed ↑ Torque ↑	Torque ↑ Speed ↓	Speed ↑ Torque ↓
36-tooth 	12-tooth 	Equal: Speed ↑ Torque ↑	Torque ↑ Speed ↓	Speed ↑ Torque ↓
12-tooth 	36-tooth 	Equal: Speed ↑ Torque ↑	Torque ↑ Speed ↓	Speed ↑ Torque ↓
60-tooth 	12-tooth 	Equal: Speed ↑ Torque ↑	Torque ↑ Speed ↓	Speed ↑ Torque ↓

G.9 cont.

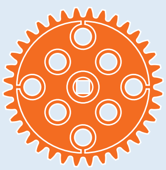
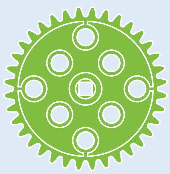
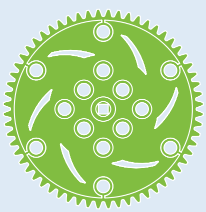
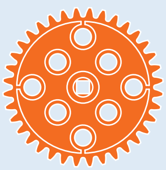
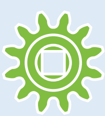
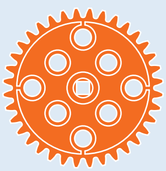
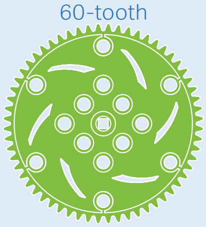
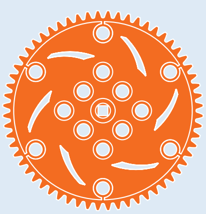
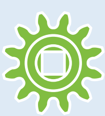
Mechanisms Gear Ratio Exercise #2: Expressing Ratio and Reduction (Grades 4-8)

Student Name(s): ____

Teacher/Class: ______________________________ Date: ______________

Instructions:

After learning about Expressing Gear Ratio and Gear Reduction from section G.3, demonstrate what you have learned by calculating and writing in correct answers. You may also build and use the VEX IQ Gear Ratio Simulator along with 12-tooth, 36-tooth, and 60-tooth gears to help find answers.

Driving Gear (Input)	Driven Gear (Output)	Gear Ratio	Gear Reduction	Simplified Gear Reduction	Is Speed or Torque increased?
36-tooth 	36-tooth 	_____ : _____	_____ / _____	_____ / _____	____________
12-tooth 	60-tooth 	_____ : _____	_____ / _____	_____ / _____	____________
36-tooth 	12-tooth 	_____ : _____	_____ / _____	_____ / _____	____________
36-tooth 	60-tooth 	_____ : _____	_____ / _____	_____ / _____	____________
60-tooth 	12-tooth 	_____ : _____	_____ / _____	_____ / _____	____________

G.9 cont.

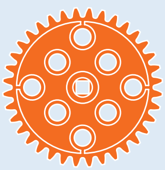
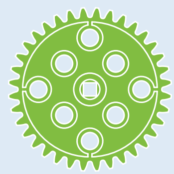
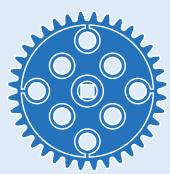
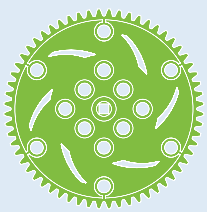
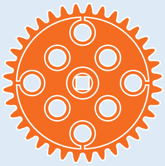
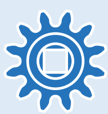
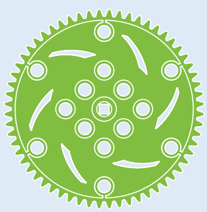
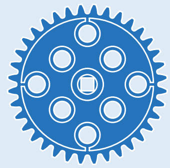
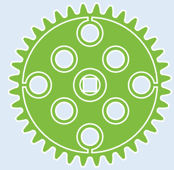
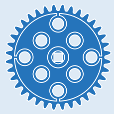
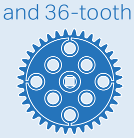
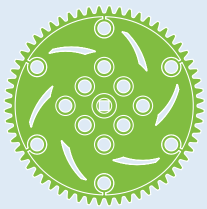
Mechanisms Gear Ratio Exercise #3: Gear Trains and Idler Gears (Grades 6-8)

Student Name(s): ____

Teacher/Class: ______________________________ Date: ________________

Instructions:

After learning about Gear Trains and Idler Gears from G.3, demonstrate what you have learned by calculating and writing in correct answers. You may also build and use the VEX IQ Gear Ratio Simulator along with 12-tooth, 36-tooth, and 60-tooth gears to help find answers.

Driving Gear (Input)	Idler Gear	Driven Gear (Output)	Gear Ratio	Gear Reduction	Simplified Gear Reduction
36-tooth 	60-tooth 	36-tooth 	____ : ____	____ / ____	____ / ____
12-tooth 	36-tooth 	60-tooth 	____ : ____	____ / ____	____ / ____
36-tooth 	12-tooth 	60-tooth 	____ : ____	____ / ____	____ / ____
12-tooth 	36-tooth 	36-tooth 	____ : ____	____ / ____	____ / ____
12-tooth 	36-tooth  and 36-tooth 	60-tooth 	____ : ____	____ / ____	____ / ____

Mechanisms Gear Ratio Exercise #4: Compound Gear Reductions (Grades 6-8)

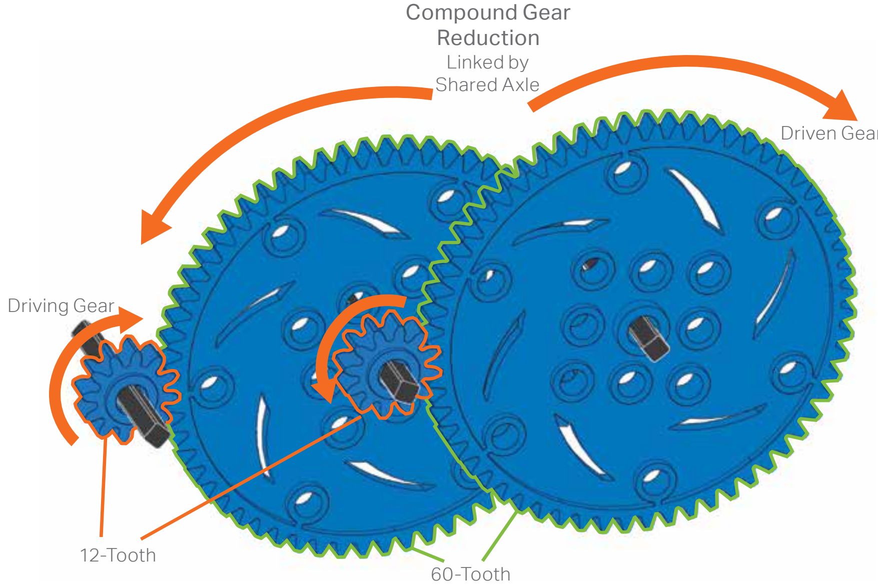
Student Name(s): ____

Teacher/Class: ______________________________ Date: ______________

Review of Key Points:

In a Compound Gear system, there are multiple gear pairs. Each pair has its own Gear Ratio, and a shared axle connects the pairs to each other. The resulting Compound Gear system still has a Driving Gear and a Driven Gear, and still has a Gear Reduction. However, it is now called a Compound Gear Reduction that is calculated by multiplying the gear reductions of each of the individual gear pairs.

For the example shown with 12-tooth and 60-tooth gears, the overall Gear Reduction is calculated this way:



(60 / 12) x (60 / 12)

↓

(5 / 1) x (5 / 1) = 25 / 1

Say "25 to 1 Compound Gear Reduction"

Instructions:

Using the information above from Compound Gears and Compound Gear Reductions (G.3), demonstrate what you have learned by calculating the correct Compound Gear Reductions. You may also build and use the VEX IQ Gear Ratio Simulator along with 12-tooth, 36-tooth, and 60-tooth kit gears to help find answers.

Gear Pair 1		Gear Pair 2				
Driving Gear 1	Driven Gear 1	Driving Gear 2	Driven Gear 2	Simplified Reduction 1	Simplified Reduction 2	Compound Gear Reduction
12-tooth	60-tooth	12-tooth	36-tooth	____ / ____	____ / ____	____ / ____
12-tooth	36-tooth	12-tooth	36-tooth	____ / ____	____ / ____	____ / ____
12-tooth	36-tooth	12-tooth	60-tooth	____ / ____	____ / ____	____ / ____