BASIC BUILDING TIPS

last updated: June 25th, 2015

TABLE OF CONTENTS

BASICS ON BUILDING SOUND STRUCTURE…

FORWARD

This document will not provide a long list of building instructions for completing a robot. This document is about strengthening your understanding in mechanical functionalities using LEGO components.

This documents' purpose is to help you in the following areas:

1. Understand basic mechanical Interrelationships.
2. Visualize mechanical movements
3. Grasp Spatial interrelationships - visualize and manipulate objects (usually geometric figures) in space.
4. Help to apply when tackling various building challenge.

Many online sites provide wealth of informative materials. However, most which are very useful are also a bit of over-whelming. They cover very rich and excellent information, but may require a more mature reading skills. Therefore, I extracted and summarized much of it and presented it in fashion which is more fun to review for Mindstorms elementary and middle school readers who may quickly get a conceptual idea.

Since most of the images are from these sites, I feel it is important to list the links here instead of at the bottom of the document. This document is meant internal reference only. Proper credits will be cited for each individual diagrams in the future. :

Most images are from:

① http://sariel.pl/– Sariel Custom LEGO Technic Creations

② http://www.education.rec.ri.cmu.edu/content/lego/

③ http://www.engineersedge.com/

④ http://www.robertcailliau.eu/Alphabetical/L/Lego/Gears/Dimensions/

⑤ http://www.me.unm.edu/~starr/teaching/lego/building.pdf (hightechkids.org)

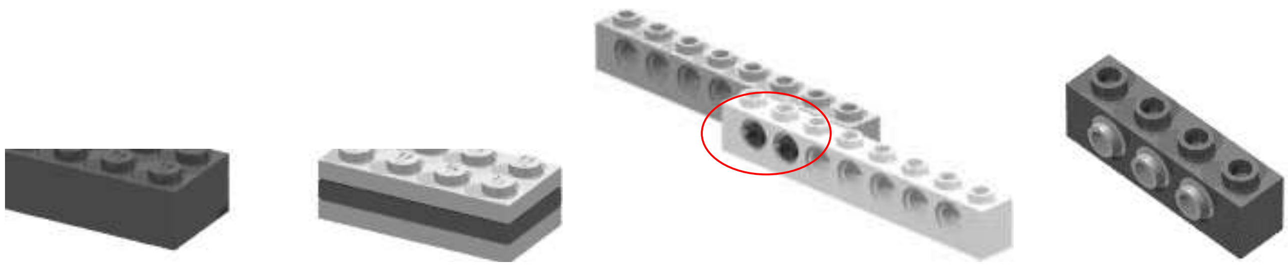
THINGS TO THINK ABOUT WHEN IT COMES TO CREATE A SOUND STRUCTURE

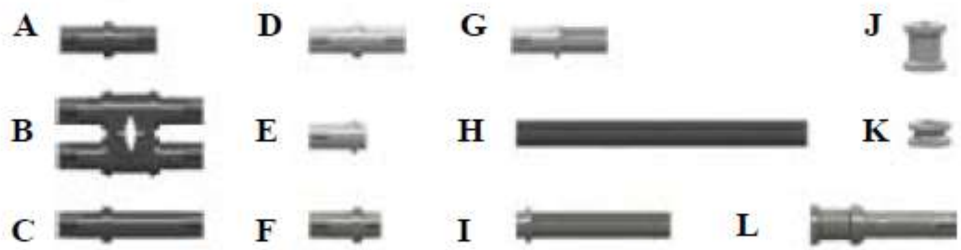
Design: • Slow vs. fast? • Gear backlash • Stability • Skidding (Tank-tracks vs. wheels) • What level of precision your gear system • Drive train – 2 or 4 wheel drive, with or without steering mechanism • Possible Work division (work concurrently) • Make testing as part of your design phase	• Modular design? • Sensors mounting • Structure and size • Strive for cool solutions, that work! Consider the aesthetics later. • Testing: • Modularize your tests • Test each module independently. • Examine the Interaction of sub-systems • Repeatability . Last but not least : **Have fun**

VERY IMPORTANT:

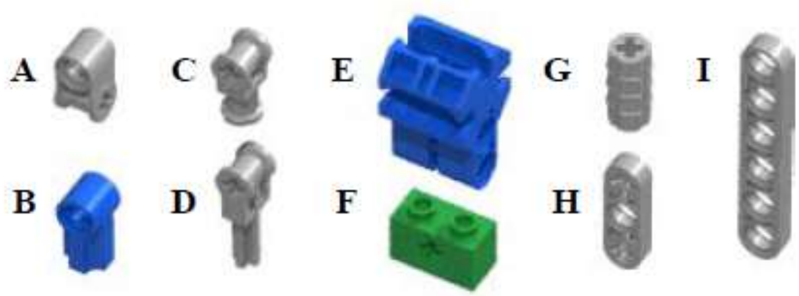
All contraptions shown in this document is meant to be just a modular prototype. The purpose is to give you important foundamental understanding mechanical functionalities. You must create your own secure structure onto your robot platform.

PLATES, BEAMS , CONNECTORS,



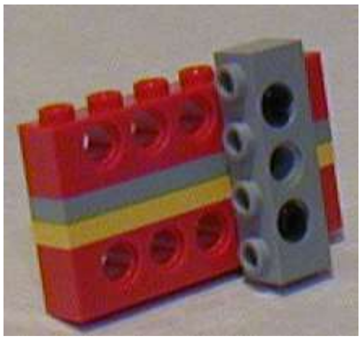
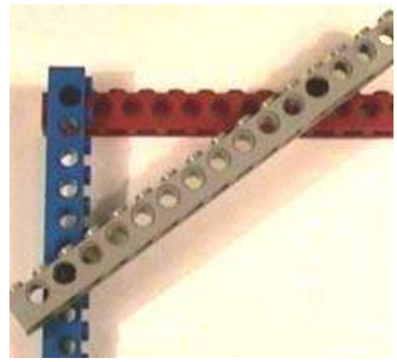
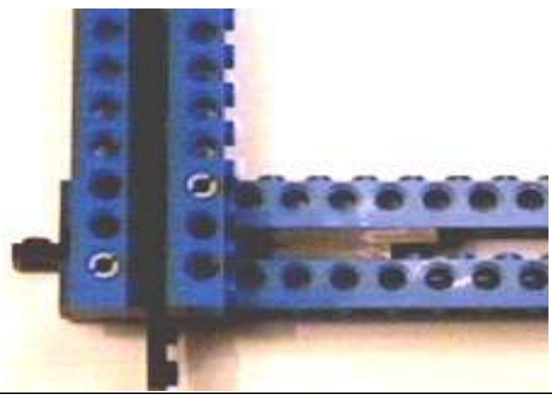
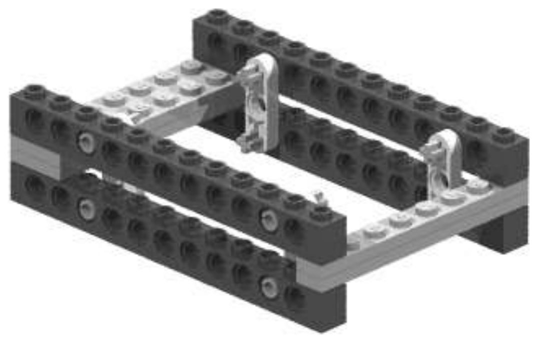


A. Pin with Friction
B. 3L Double Pin
C. Long Pin with Friction
D. Technic Pin
E. Half Pin
F. æ Pin
G. Axle Pin
H. 6L Axle
I. 3L Pin with Stud
J. Full Bushing
K. Half Bushing
L. Long Pin with Stop Bushing

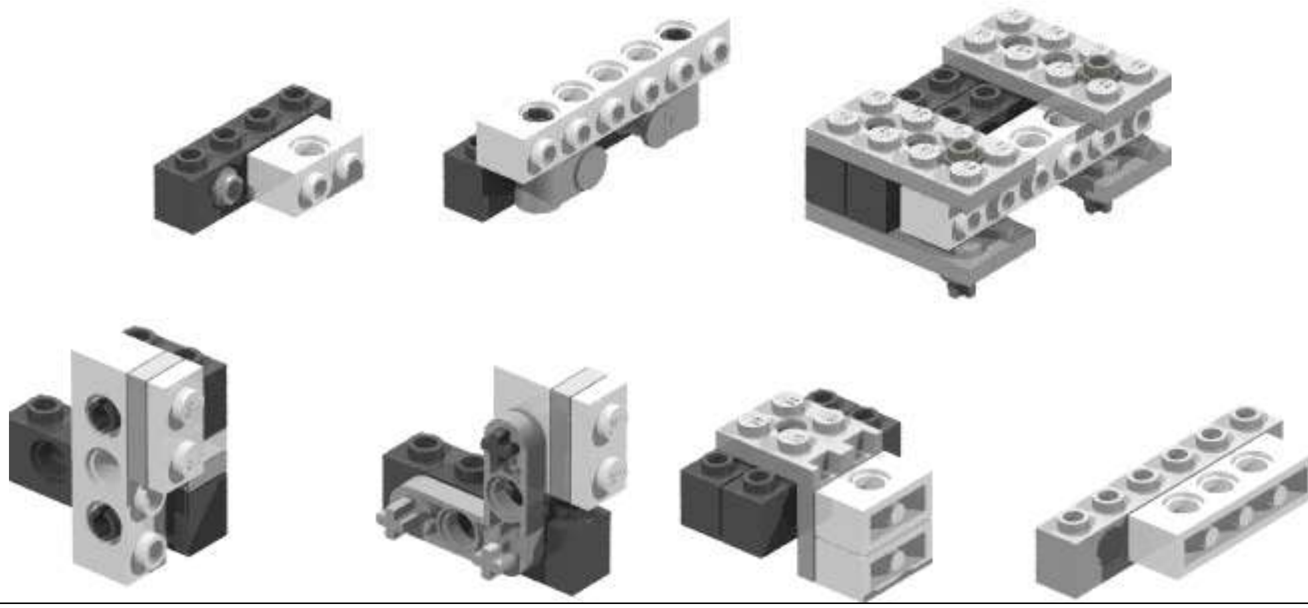


A. Axle Jointer Perpendicular
B. Angle Connector #1
C. Connector with Axlehole
D. Pole Reverser Handle
E. Connector Block 3 x 2 x 2
F. Beam 1 x 2 with Axlehole
G. Axle Joiner
H. Liftarm 1 x 3
I. Liftarm 1 x 6

BRACING AND INTERLOCKING

Notice that there are 2 plates in-between. 	Simple triangular bracing 
Interlocking it. 	Cross Braced Frame 

Turning 90 degrees – studs out

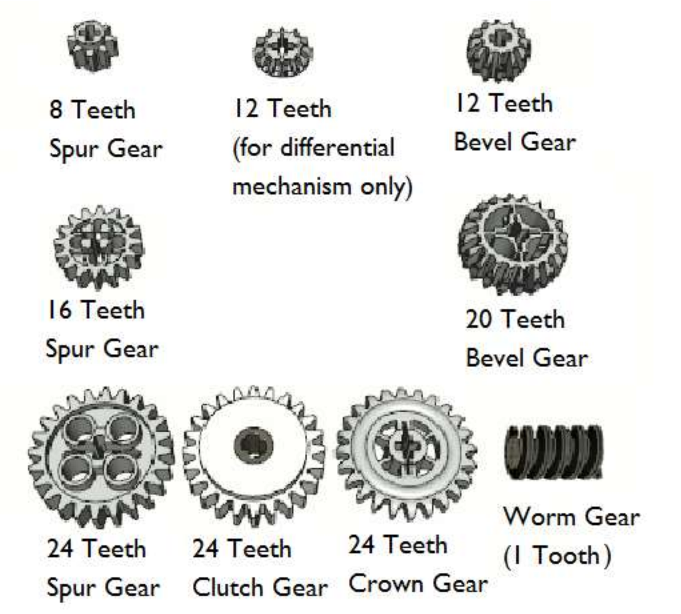


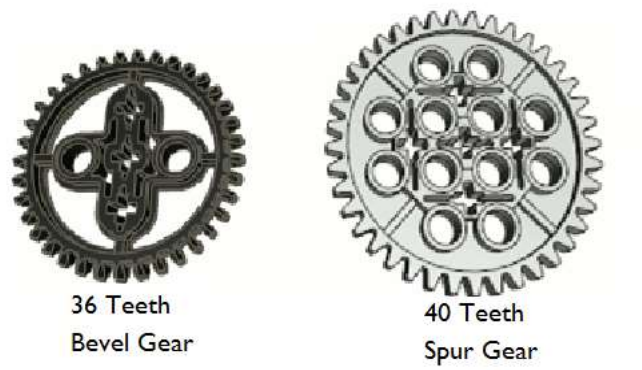
Turning 90 degrees – studs in 	Upside down 	Extension 
	Use Cross-axle connections This can can lock beams at fixed angle, and keep them from spinning.	

BASICS ON GEARS

Importance in combining the gears is to transfer motion and gain mechanical advantage

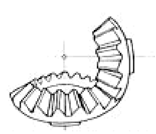
TYPES OF GEARS



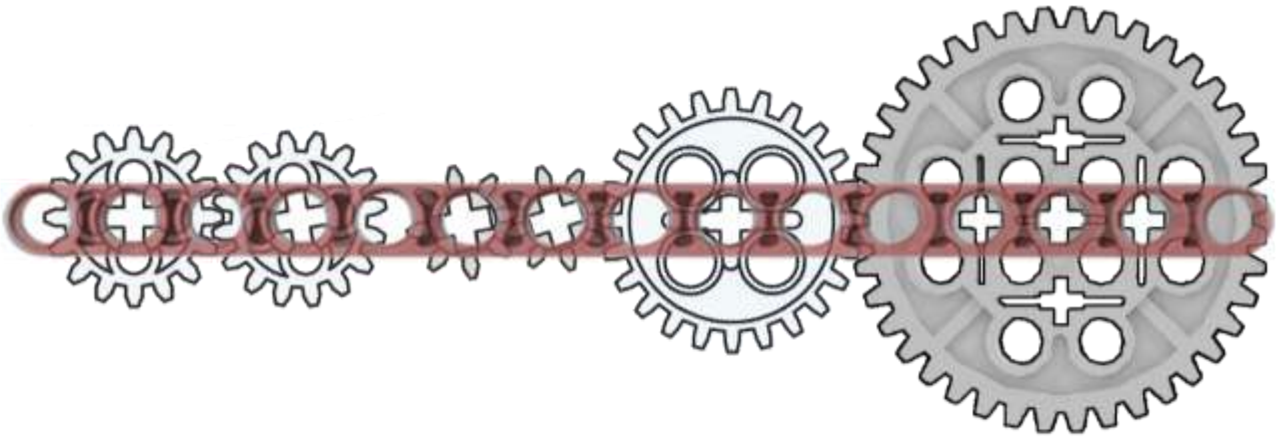


Rack pinion

Ball Gear

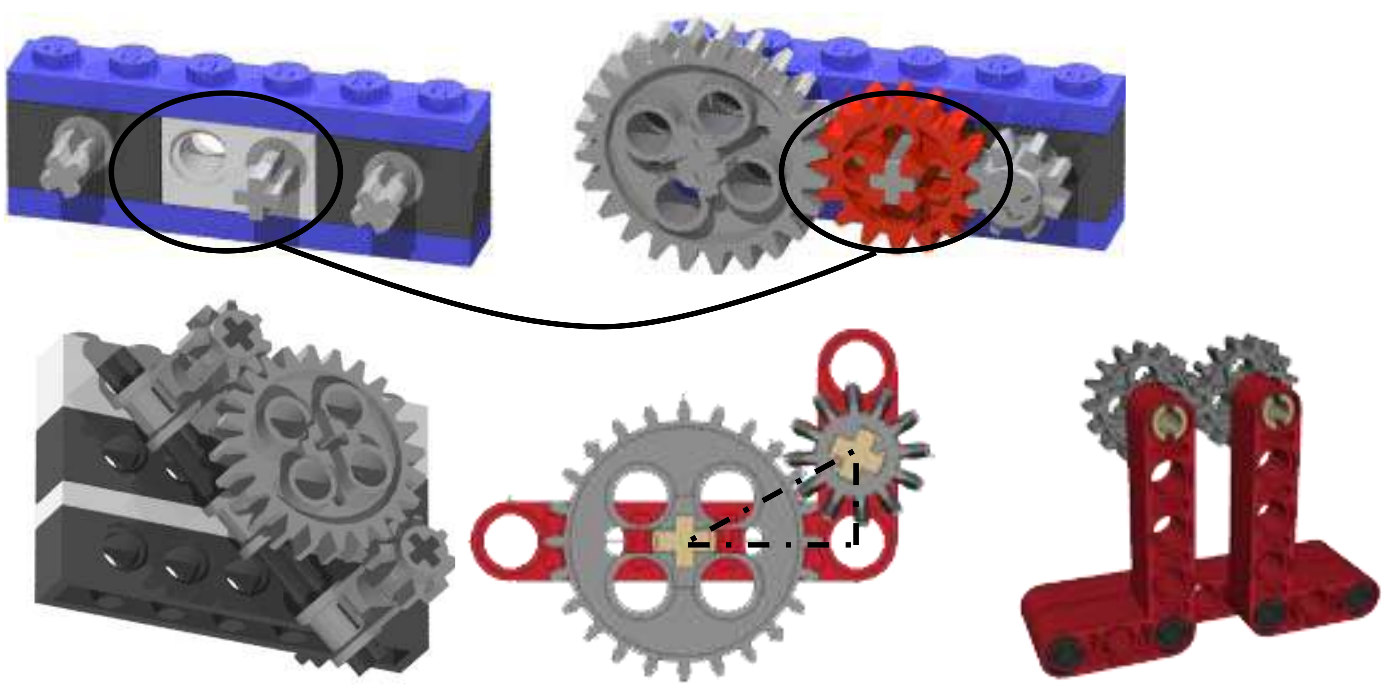
Spur	For linear mounting, i.e. side by side.	Crown	Allow 90 degree mounting
Worm	Provide locking system	Clutch	Like Spur gear, but allow slippage as the axle hole is made of softer materials
Bevel	Provide features from both a spur and crown gear. There are various types of bevel gears. LEGO bevel gear transmit motion between shafts with intersecting center lines 	Ball	Allow easy turning. But, not for precision.

Gears Spacing



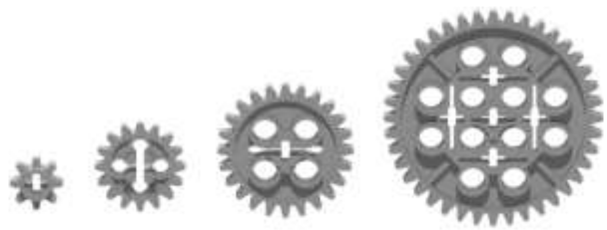
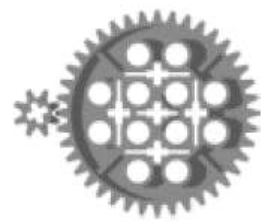
Odd Gear Spacing

Images from ①



SIMPLE GEAR RATIO

This applies to any type of gears.

8-th 16-th 24-th 40-th 	Drive Follower  8:16 or 1:2  8:24 or 1:3  40:8 or 5:1
Gear Ratio = 8: 1 (from 24 : 8) gear down to gain torque	Driver = 8-th Follower=24-th 
Gear Ratio = 1 to 8 (from 8:24) gear up to gain speed	Driver = 24-th Follower=8-th 
Gear ratio = 1 : 1 The 24-tooth gear in the middle does not affect the gear ratio. Thus, it is called idler gear. See more samples below	

COMPOUND GEAR RATIO

Before you calculate gear ratio, identify the driver and follower pairs first.

<table>
<tr>
<td>Gear ratio = 9 : 1

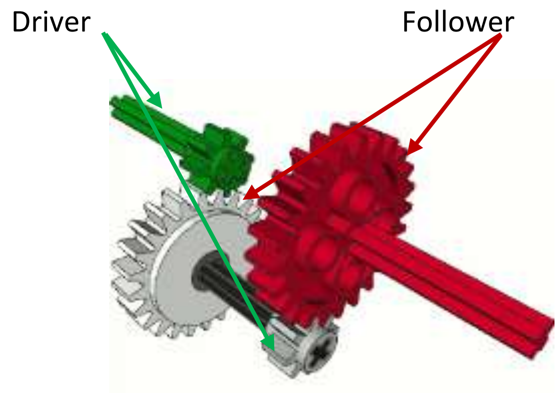
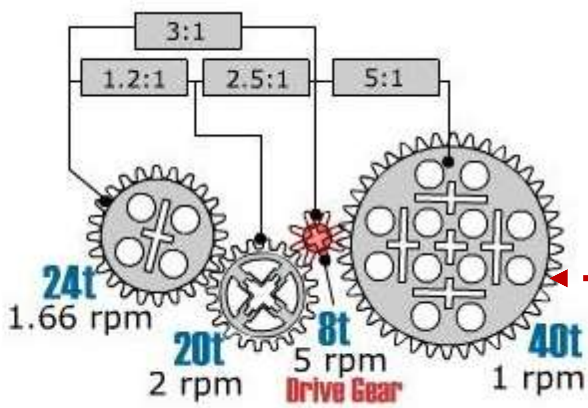
From 24/8 x 24/8</td>
<td>
</td>
</tr>
<tr>
<td>Trading off between Speed and Strength (Torque)
To reduce speed == increase torque


Image from ③</td>
<td>Trading off between Speed and Strength (Torque)
To increase speed < ----- > reduce torque

Just make the 40-th gear to be the driver instead.</td>
</tr>
</table>

MULTI-STAGE GEAR TRANSMISSION SYSTEM

To achieve extreme gear ratio, you should create a multi-stage instead of a linear fashion, i.e. one next to each other. Doing one next to each other greatly reduce efficiency, far worse than multi-stage.

Image from ⑤

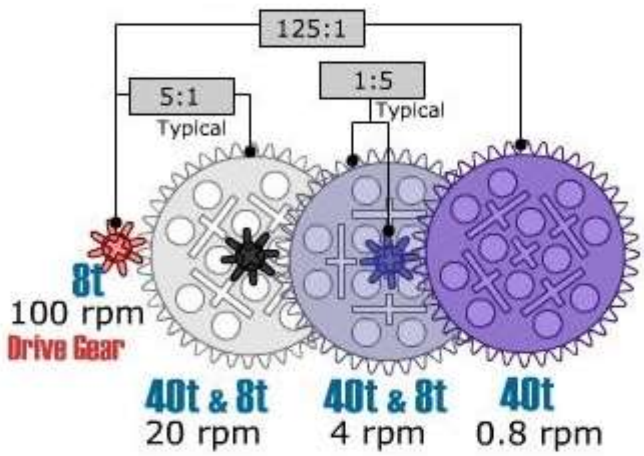


Image from ③

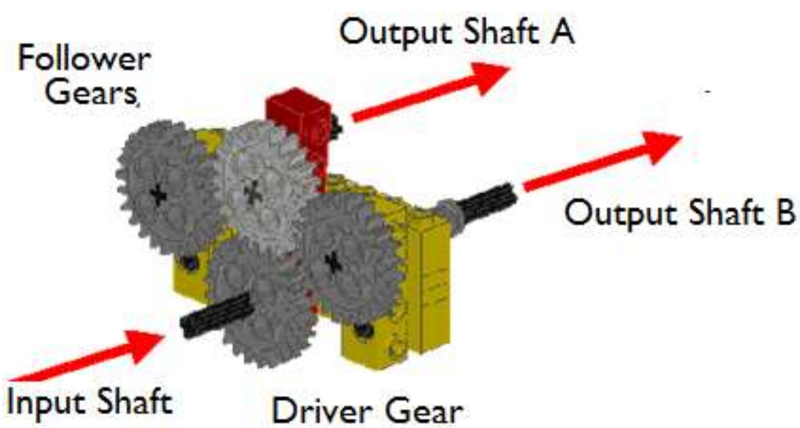
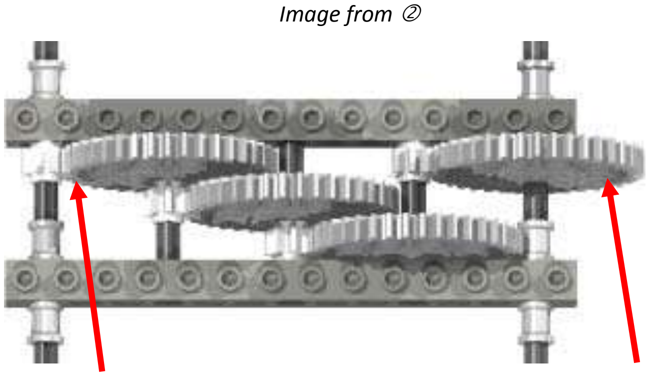
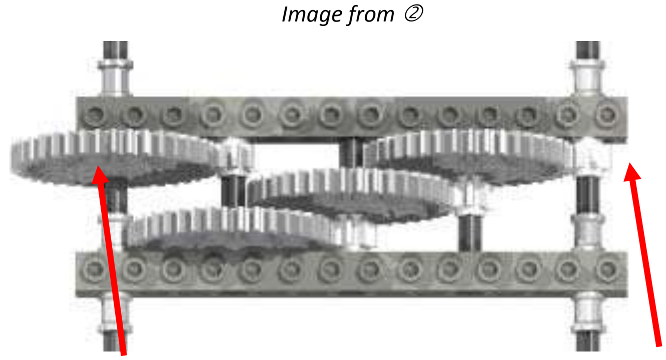


Image from ②



Driver (input shaft) Output shaft

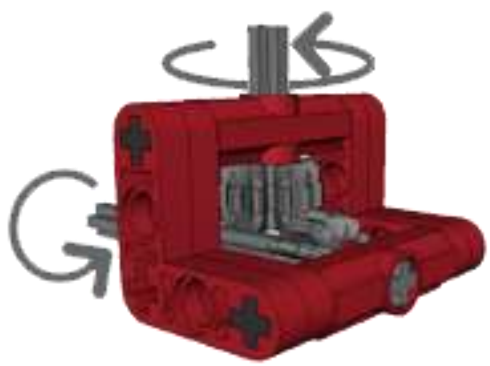
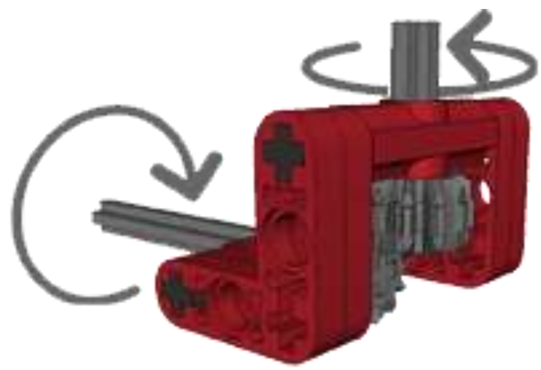
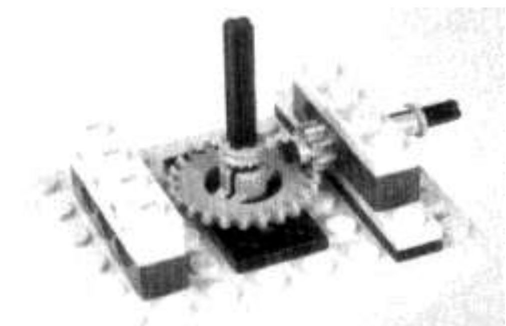
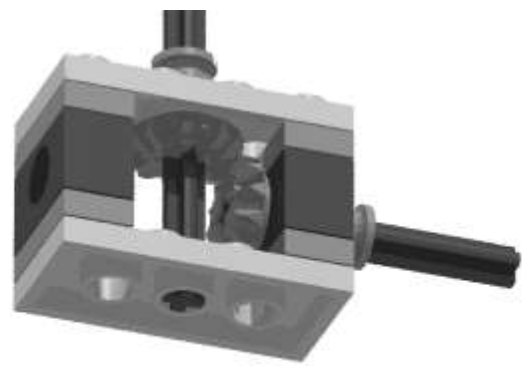
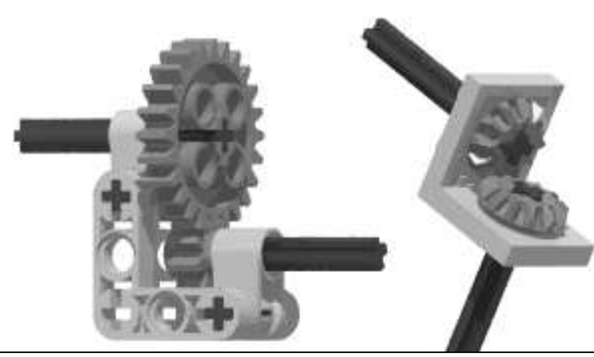
Image from ②

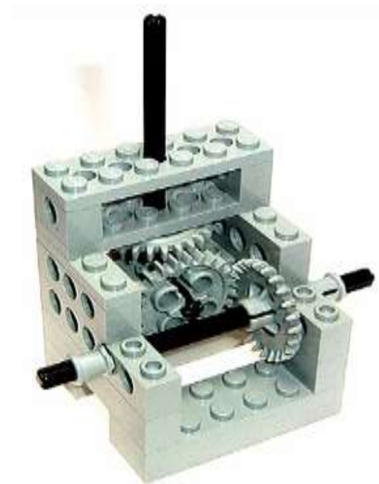


Driver (input shaft) Output shaft

Gear Ratio = 625 : 1	Gear Ratio = 1 : 625

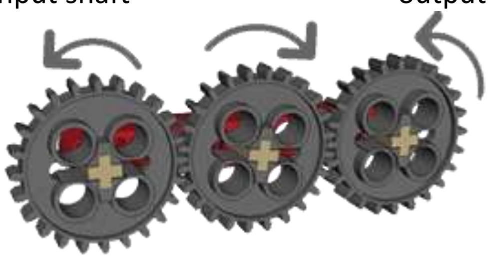
USING GEARS TO FORM MOVEMENTS ON 2 DIFFERENT PLANES

<table>
<tr>
<td>Image from ④
</td>
<td>Image from ④
</td>
<td>Image from ④
</td>
</tr>
<tr>
<td colspan="2">Changing rotational axis
Image from ④

.</td>
<td>Image from ②
With simple gear box
</td>
</tr>
<tr>
<td colspan="3">Securing the two gears
Image from ②
</td>
</tr>
</table>

<table>
<tr>
<td>Movements on 3 planes
</td>
<td>Movements on 3 planes with gear box

NOTE! You will need to create a gear box structure good enough to hold these 3 axis movement in place. This image is just simply a proto-type to get the concept across.</td>
</tr>
</table>

The Idler Gear

<table>
<tr>
<td>Notice the middle one's role is to transmit the motion. It does not change the gear ratio between the input and output shaft. Also, watch the rotational direction!

Input shaft output shaft
</td>
<td>Idler gear


NOT idler gears
</td>
</tr>
</table>

USING WORM GEAR

Using Worm gear as the locking mechanism. Worm has to be the driver, not follower. This is used as a good locking system, such as a Claw, joint like an elbow, crane, etc.

<table>
<tr><td>Changing rotational axis
Image from ②

</td><td>There is a 24-tooth gear behind the triangular bracket.

Gear Ratio 24 : 1

There is a 12-tooth gear behind the triangular bracket.

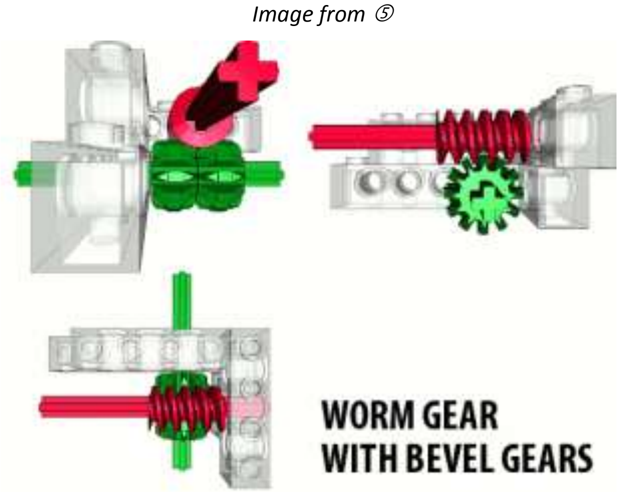
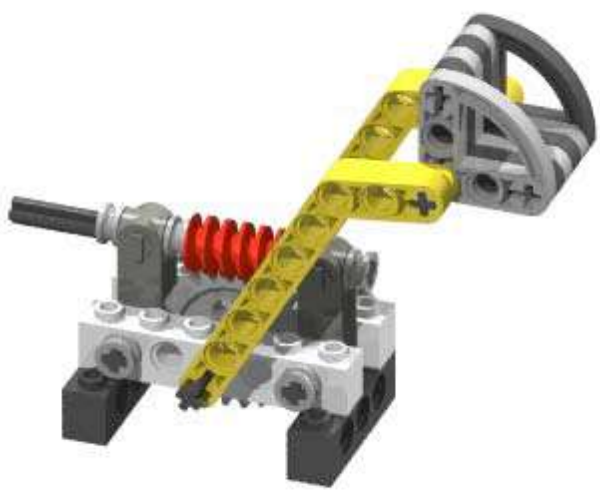
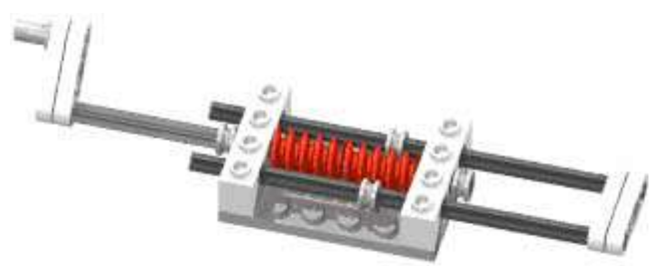
Gear Ratio 12 : 1</td></tr>
<tr><td>Another way to mount the worm gear with a spur gear
Image from ①
</td><td>Image from ⑤
</td></tr>
</table>

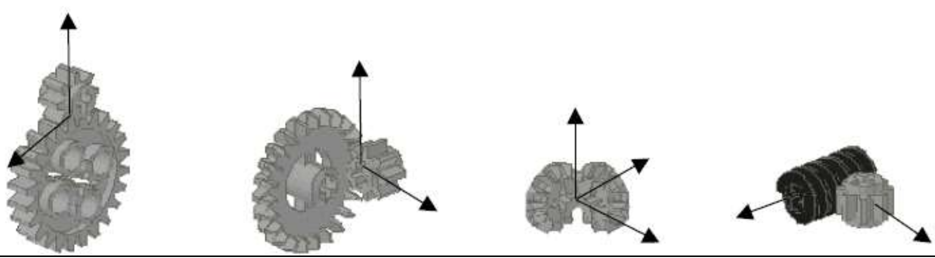
Image from ① 	The worm must be the driver gear! There are two 24-tooth gears.. So, the two output shaft (24-t) spins in the same rate. .
Attention! Just like anything else, this is only a prototype. Since this is meant to lift heavy object, this structure requires strong bracing and secured on a platform *Image from ②* 	Lead screw *Image from ①*    Good bad

RACK PINION

Image from ②

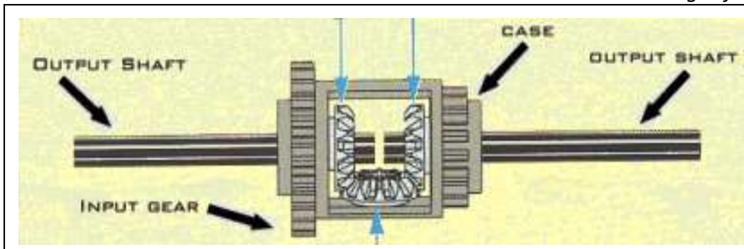
FORCES ON GEARS

Images from ①



DIFFERENTIAL GEAR

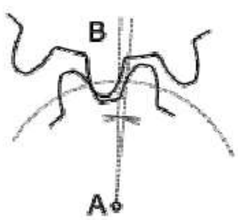
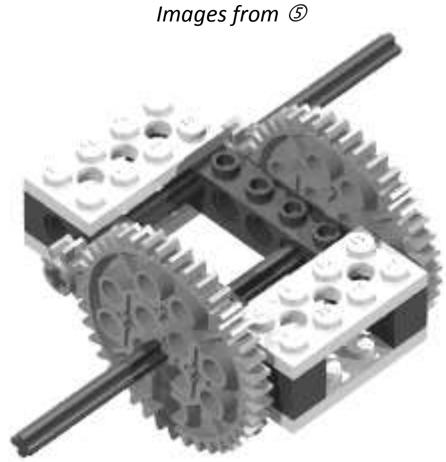
Images from ⑤

	A differential is a device which applies torque evenly distributes it to two output shafts. Besides, it also allows each output to spin at a different speed.
	Attaching a rotation sensor to the differential housing would provide a MORE accurate measure of travel distance.

BACKLASH ISSUE

Usually not an issue unless your automated system requires a lot of accuracy .

If you are in a competition like Robocupjunior, it is not so much an issue as you may use various sensors to increase accuracy to interact with an environment with a lot of variable elements. Unlike First Lego League, this game has a lot of pre-defined elements, ie. Location and dimensions of objects are all pre-defined. You are not allowed to use non-lego sensors, nor most even 3rd –party lego compatible sensors. Accuracy of movement is extremely important in order to achieve consistent result.

Backlash Problem	One Way to minimize backlash
Images from  Caused by poor gears meshing!	*Images from* 

REDUCING BACKLASH:

- Gear down if possible.
- Avoid diagonal mounting, unless you can mount it in perfect distance.
- Bigger the gear,the less backlach effect
- Minimize the linear mounting of many gears in a row. The backlashes effect of meshed gears sum up. Go for Multi-stage.
- Create a gear-up system for the rotation center to increase accuracy
- Use Bevel gear. Do not use worm gear unless you have to.

EFFICIENCY

Efficiency of the gear == amount of power is transferred. As long as there are gears meshed together, it losses some efficiency due to the friction due to the weight, and backlash issues. Same guideline is used for this to minimize backlash.

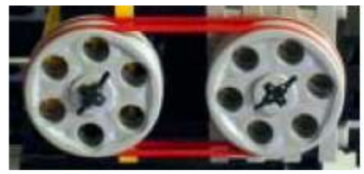
PULLEY

This provides similar functions like gears, except pulleys allows much slippage, but very flexible on the distance between input and output shaft.

Example:

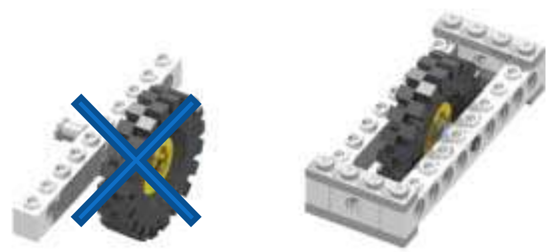
Rotate opposite direction

Rotate same direction

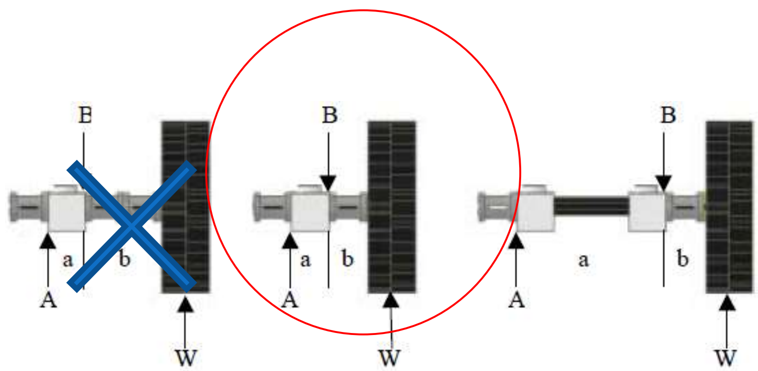


WHEEL LOADING AND FRICTION

Images from ⑤



Typical Cantilevered and Fully Supported Wheels



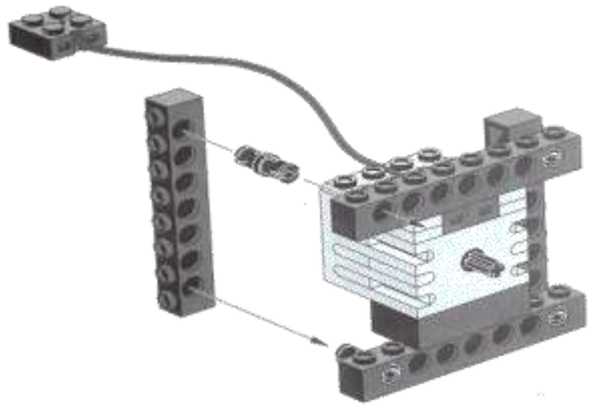
Keys:

1. Placing the wheels close to the frame
2. Spreading out the axle supports to reduce the forces required to react the moment from the wheel.

MOTOR BRACING

The new mindstorms need to allow much more secured bracing. However, they are indeed much too much for some light weight work. If you use one of the RCX style motor, you must brace it very well.

Images from ⑤



SENSORS

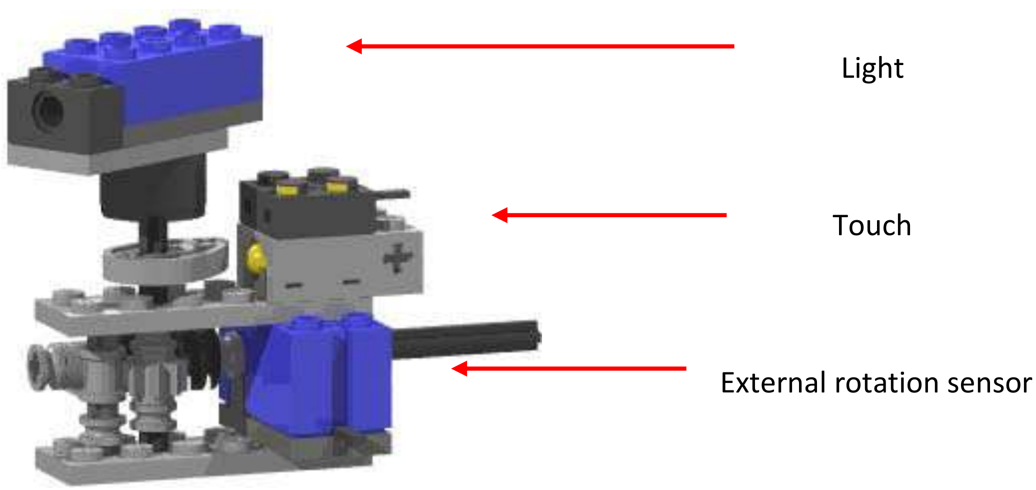
Images from ⑤

TOUCH BUMPER



Smart way to preform multiple functions – Detect light reflection, rotation precision. Then, with the touch sensor, it can perform reset in order to remove accumulative errors. Very smart contraption.

Images from ⑤



Sensors here are from the older RCX set. They work just as good as the NXT or EV3 versions. These are sometimes more preferrable due to their small sizes. Besides, you can multiplex the touch and light sensor on the same port. With the NXT or EV3 ones, you cannot do that.

ROTATION SENSOR

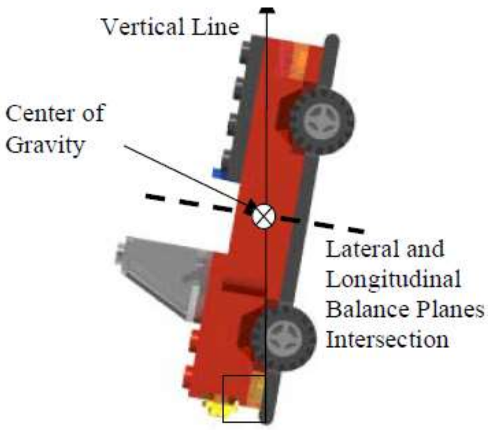
A Bumper contraption mounted with a rotation sensor, you can tell exactly how far the obstacle is in front of you.

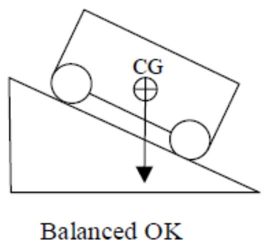
MULTIPLEXING LIGHT AND TOUCH SENSORS

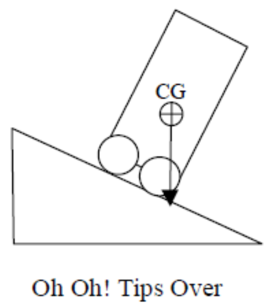
	Open	Touch closed	Light sensor
Touch	0	1	Light level
Light reading	Light level	100	Unknown, but that's ok as this design is meant to detect obstruction.

ROBOT DRIVE

To maintain balance, the CG must remain well inside the wheelbase. If it is outside the wheelbase, the robot will tip over. The closer the CG is to the center of the wheelbase, the more stable the robot becomes.





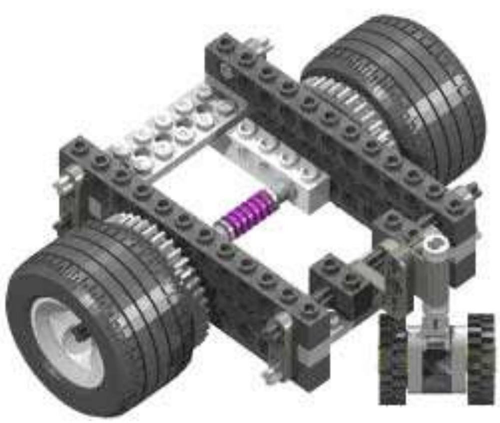


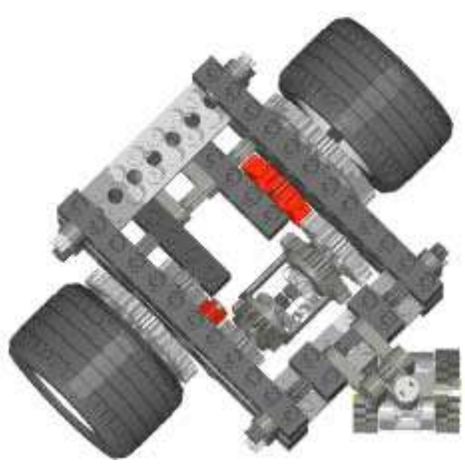
DESIGN TO HELP GOING STRAIGHT:

Using a slip limiter

Locking differential

Image from ⑤





Slip limiter : The longer the length of axle inside the hose the more torque is transmitted. This can help to transfer speed to the other wheel.	Locking differential: to eliminate slip between the left and right drive wheels. It forces the two independent axles to behave like a solid axle.

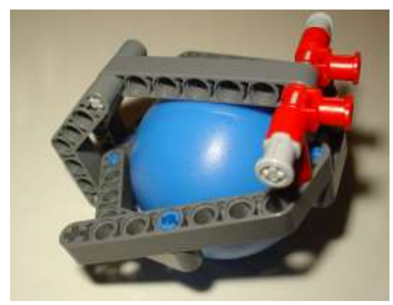
You may also use PID motor feedback control in your program to sync up the motors. However, no matter what, this cannot overcome uneven terrain. Thus, a type of orientation sensing device is needed if orientation is important to your robot.

USING CASTER SUPPORT

Pivotal caster wheel allows easy manuverability, but inaccurate turn. Caster ball will reduce the accuracy of turning.

Image from ⑤



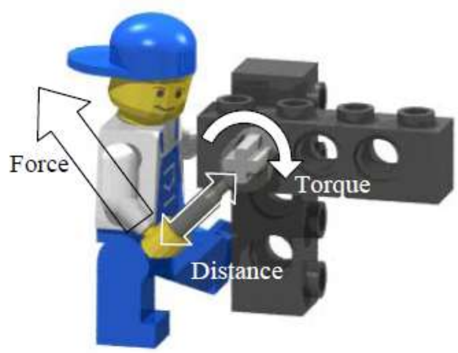


CALCULATING TORQUE

Coming soon!

Torque = rotational force

Image from ⑤



= force x distance

DESIGN CONCEPTS BY MIT MEDIA LAB

Doesn't matter it is LEGO or other components. Basic mechanical principles apply to all components:

Keep in mind these few universal engineering principles when building your robot. We've seen, in every contest we've run, that teams who do well all follow these (sometimes, to extremes!).

- **Simplicity.** The best way to build a reliable robot is to keep it as simple as possible. The more complicated a design is, the more prone it is to failure, and the harder it is to adapt when your ideas change. It is generally better to build a part that works in most cases all of the time rather than all cases most of the time.
- **Strength.** Investing time in sound robot construction will save you *lots* of time and suffering in the future. LEGO is a great medium for rapidly building a robust robot, but only if braced properly. Even when prototyping parts for your robot, build them for strength.
- **Modularity.** Often, it will be necessary to upgrade or repair a component of the robot, but if the robot is built as one monolithic unit this may make it necessary to disassemble a substantial portion of the structure. If, however, you design your robot as a group of connected modules, modules can simply be removed and rebuilt as needed.

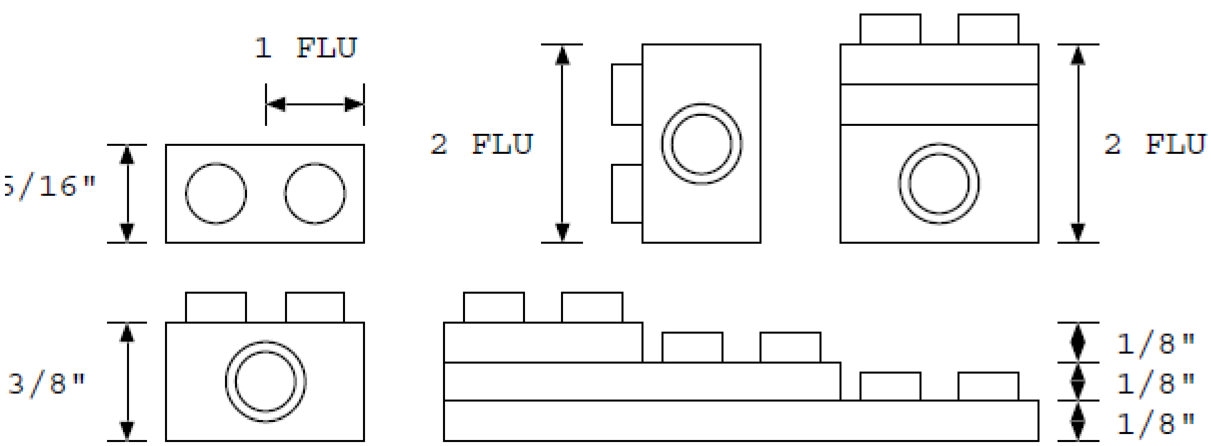


Figure 1: LEGO Dimensions

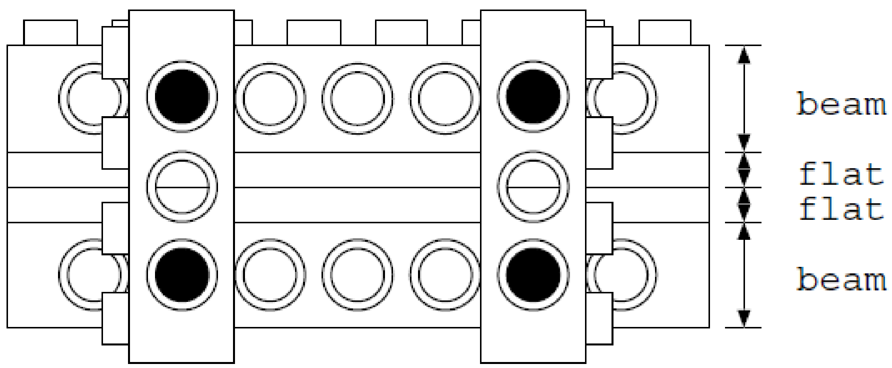
BEAMS, CONNECTORS, AND AXLES

One of the most important types of parts in the LEGO Technic system is the beam. Beams are long structural pieces with holes through their sides. Besides their obvious use as structure components, they can be used in conjunction with other pieces to build elaborate structures.

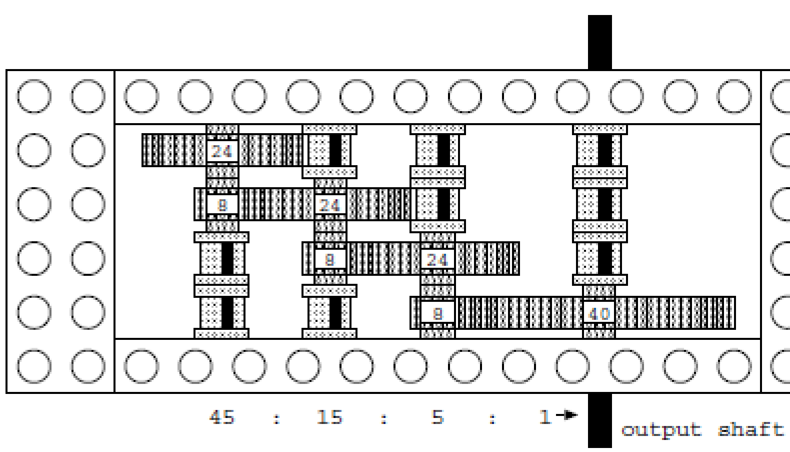
Connectors allow you to stack beams side-to-side by spanning the holes of adjacent beams. Bracing a side-to-side joint across two holes will provide a stable beam structure, while using only one joint will allow you to create diagonal structures and moving joints. Imagine the possibilities!

Note that the two types of connector are functionally different. The black ones fit more snugly into the holes and resist rotation. The gray ones, on the other hand, rotate freely inside the holes for use in moving parts. It is alright to use the gray connectors in place of the black ones, but using a black connector in a moving joint will damage the connector and hole.

The holes through the beams also serve a further function when coupled with axles. The axles can be passed through a hole, and if supported properly between multiple beams, can rotate freely.



SAMPLE GEARBOX WITH COMPOUND GEAR TRANSMISSION



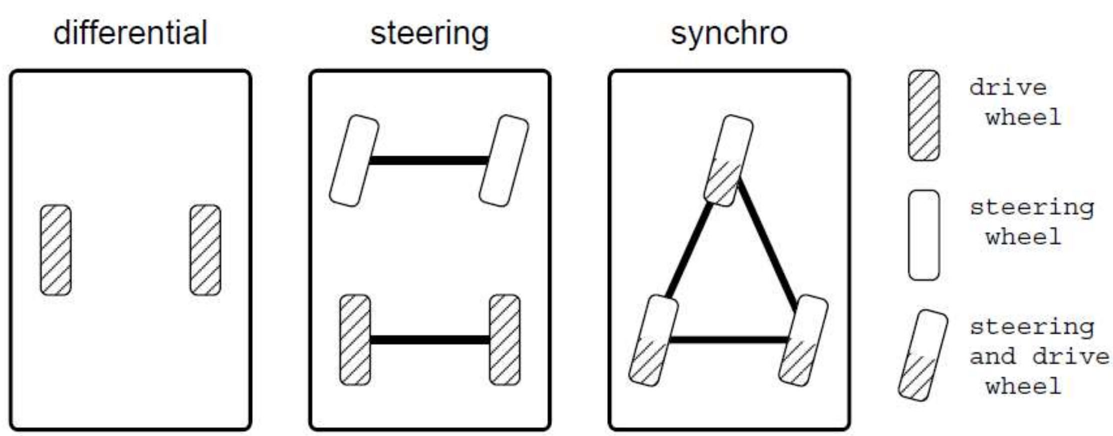
EFFICIENCY

The biggest enemy of any gearbox is friction. Every place where something rubs, energy is lost which makes your robot slower and weaker. In the short-run, this causes your robot to perform poorly and seize up, but in the long-run, it will cause wear and tear on the moving parts. More damage means more friction, and after awhile, the gearbox will stop working. In order to minimize the amount of friction in your gearbox and maximize its efficiency, follow the tips below:

1. The spacing between gears is very important. If they are too close to each other, they will bind up. If they are too far, the teeth will slip past each other. Make sure that gears are spaced at exact LEGO dimensions and avoid meshing gears at an angle.
2. 2. The axles are made out of plastic and can bend if not properly supported. Try to always support the axle between two beams and do not place a gear more than one space outside of the supports.
3. The gearbox will often be subjected to stresses when used within a robot. Make sure that the beams supporting the axles are attached to each other with more than one cross-support and that the whole structure is braced. If the beams are not perfectly parallel, the axles will rub against the insides of the holes.
4. 4. During operation the gears can slide along the axle or bump into nearby gears. Use spacers to fill in any empty spots along the axle.
5. 5. Make sure that the axles can slide back and forth a tiny bit. If they cannot, the gears or spacers are probably pushing up against a beam. This is probably the most common (and easiest to fix) mistake which saps efficiency from a gearbox. If you want to know how good your gearbox is, try backdriving it. Remove the motor and try to turn the output shaft (the slow axle) by hand. If your geartrain is efficient, you will be able to turn all the gears this way, and if it is really efficient, they should continue spinning for a second or two after you let go. If your gearbox cannot be backdriven, something may be wrong with it.

DRIVE MECHANISMS

Perhaps the single most important aspect of a robot's physical design is its drive system. It is responsible for moving the robot from place to place by providing the appropriate motive force and steering mechanisms. Figure 5 shows the three most popular drive arrangements.



GEAR RATIO EXERCISES

SIMPLE GEAR RATIO

Gears go together in groups of two or more. One gear turns another, which may turn another, and so on...

To begin our investigation of gears, let's first decide how many different possible combinations of two gears there are.

Obtain each one of the following:

- 40-tooth Gear
- 24-tooth Gear
- 16-tooth Gear
- 8-tooth Gear
- A beam longer than 10-stud (with holes)
- four #8 axles.

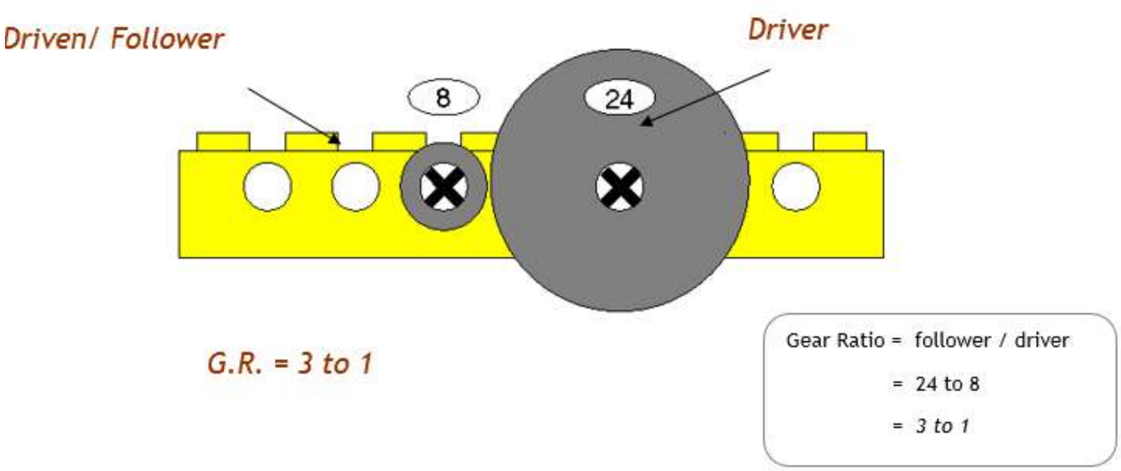
Key focus:

6. Find out different pairs of gears (two gears together) you can make using these 4 sizes.
7. How many holes to leave between gears so that they will mesh together.
8. Draw the different gear combinations in the following pages.

Note:

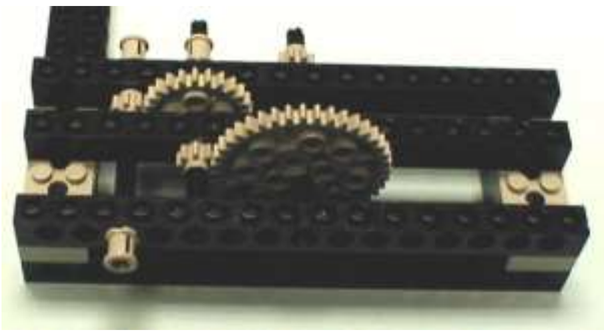
- Don't forget to include pairs where the gears are the same size!
- Put a cross in the hole to represent axle.
- Draw circles to represent the gears.
- Write down gears ratio next to it.

Example:

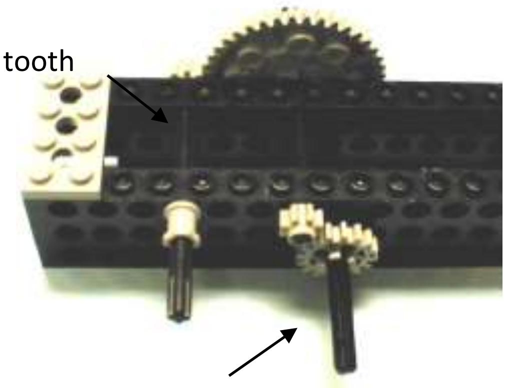


COMPOUND GEARS RATIO

1. What are the compound gear ratios of these gearboxes? The input axle is on the left, and the output axle is on the right.



16 tooth



16 tooth

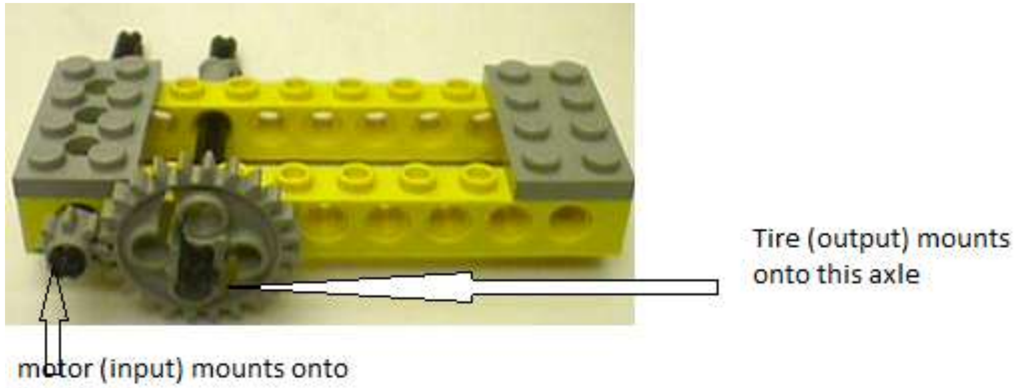
2. Explain, in your own words, what a force is.

3. What are the two components of work?

4. You have a gearbox that is closed, you can't see the gears. However, you know if you turn the input axle with a torque of 2 Newton-meters, you measure a torque on the output axle of 100 Newton-meters. What is the gear ratio? (Assume negligible friction). Is the output axle turning faster or slower than the input axle?

5. BONUS FOR CAR DRIVERS. If you have a car with a manual transmission, you know you have to put the car into 1st gear, then change to 2nd, then to 3rd, etc. Why do you think you have to do this?

6. Given the following information:

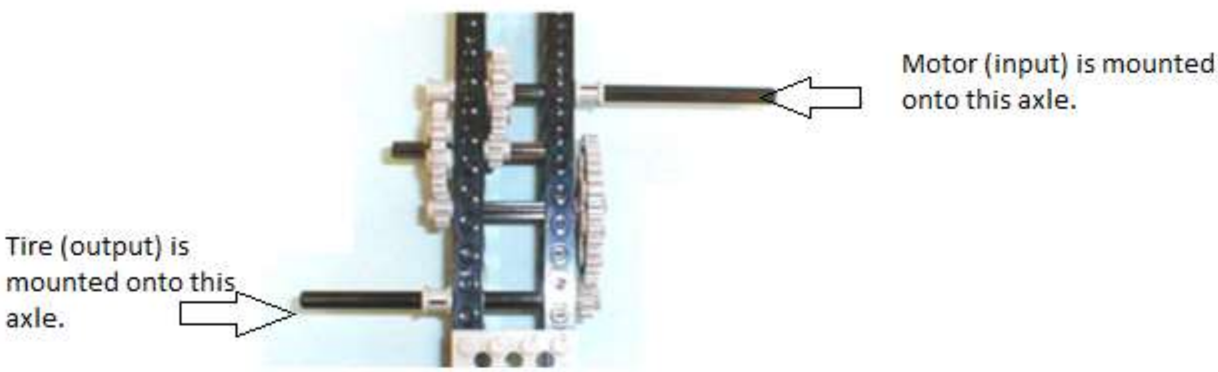


a)
b) Tire measures 14cm diameter.

Calculate the distance traveled when:

- When Motor turns 360 degree, it travels ______________cm.
- When Motor turns 180 degree, it travels ______________cm.
- When Motor turns 45 degree, it travels ______________cm.

7. Given the following information:



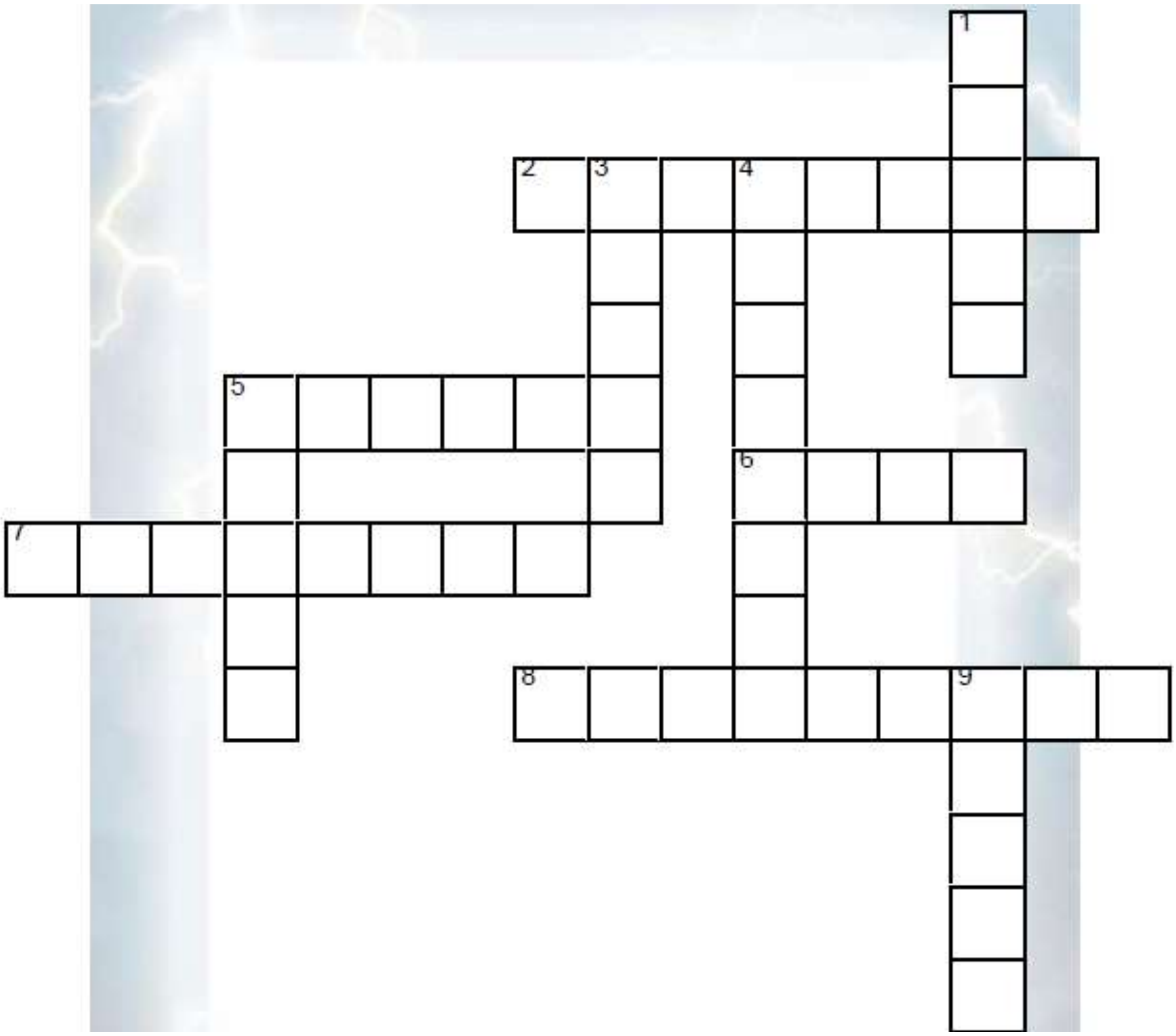
a)

b) Tire measures 14cm diameter.

Calculate the distance traveled when:

- When Motor turns 360 degree, it travels ______________cm.
- When Motor turns 180 degree, it travels ______________cm.
- When Motor turns 45 degree, it travels ______________cm.

FUN GEARS PUZZLE



speed idler geardown opposite third direction same stronger faster force

Across

2. When gears have higher turning force, it means it is ____________.

5. When gears have higher turning speed, it means it is ____________.

6. When two gear wheels are mounted on the same axle, they turn at __________ speed.

7. A smaller gear "drives" a bigger "gear". This will make it ____________.

8. You use gears to change the ________________of rotation.

Down

1. You use gears to increase or decrease the _____________ of rotation.

3. When you put three gears together, the first gear turns the same direction as the ___________ gear.

4. When you put two gears together, they turn ___________ direction.

5. You usually lose in turning _____________ when you gain in turning speed.

9. The name for a gear that is meshed between a driver and a follower gear.