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سایت آموزش مهندسی مکانیک ایران

# Teaching Gear Theory to Students

For FLL and FIRST



# What We Will Talk About

- Discussion of gears especially for FLL
- Will have parallel topic for FIRST
- For LEGO® gears, will use LDraw names
- Will have a demo area here on the gears

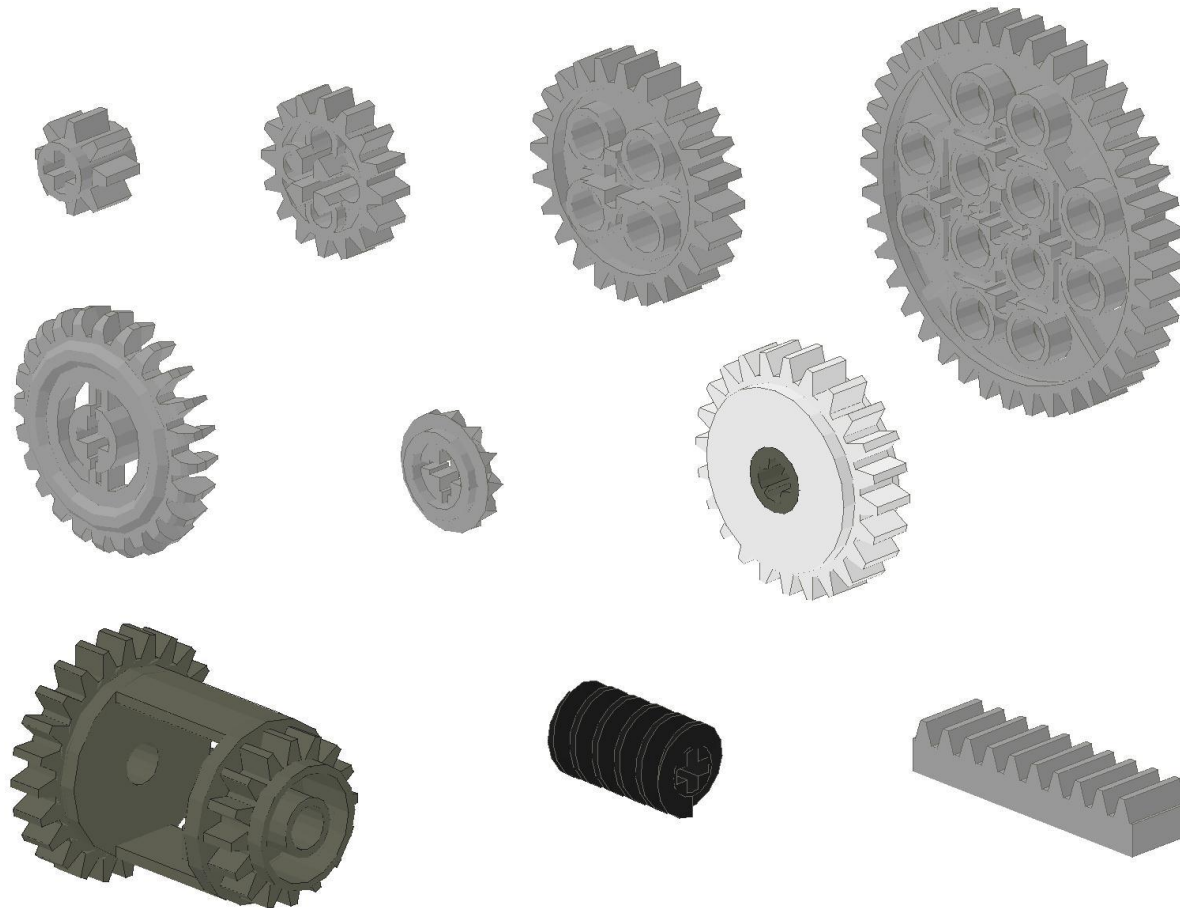
# Main Lessons to Teach in Gears

- Terminology in Gears
- Identification of Gears (Types)
- Basic Properties of Gears
- Gear Geometry
- Gear Analysis (Gear Ratios)

# Basic Gear Types in LEGO® - 1

- In the Robotic Invention System 2.0 (t=tooth)
  - Spur gears (8t, 16t, 24t, 40t)
  - Crown/hybrid gears (24t)
  - Bevel gear (12t)
  - White Clutch gear (24t)
  - Differential gear (16t & 24t on casing/shell)
  - Worm gear (1t)
  - Rack gear

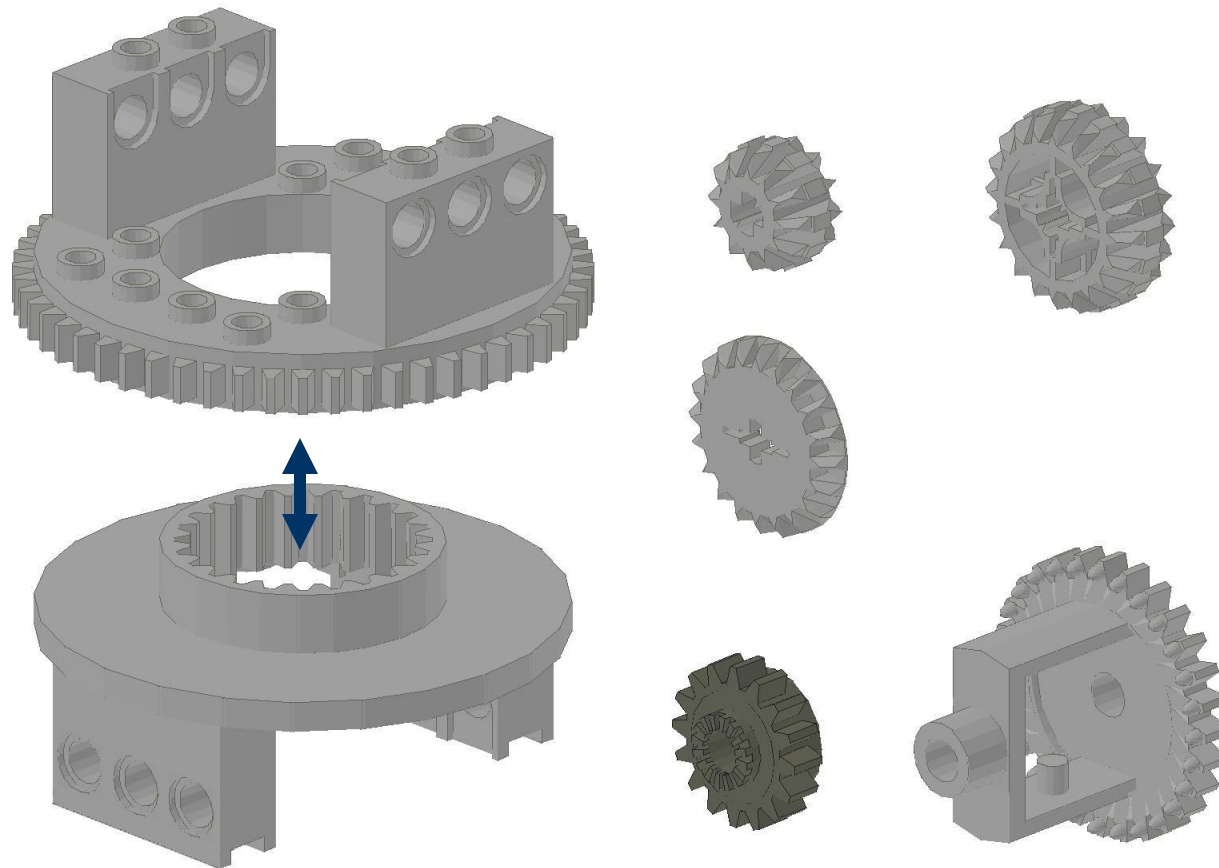
# Pictures of Gears in RIS 2.0



# Basic Gear Types in LEGO® - 2

- In Sets Other than RIS 2.0 (still available)
  - Bevel Gear (20t)
  - Double Bevel Gears (12t, 20t, 36t not pictured)
  - Turntable (56t)
  - Old Differential Gear (24t on casing)
  - Technic Gear 16t with Clutch

# Pictures of Gears NOT in RIS 2.0



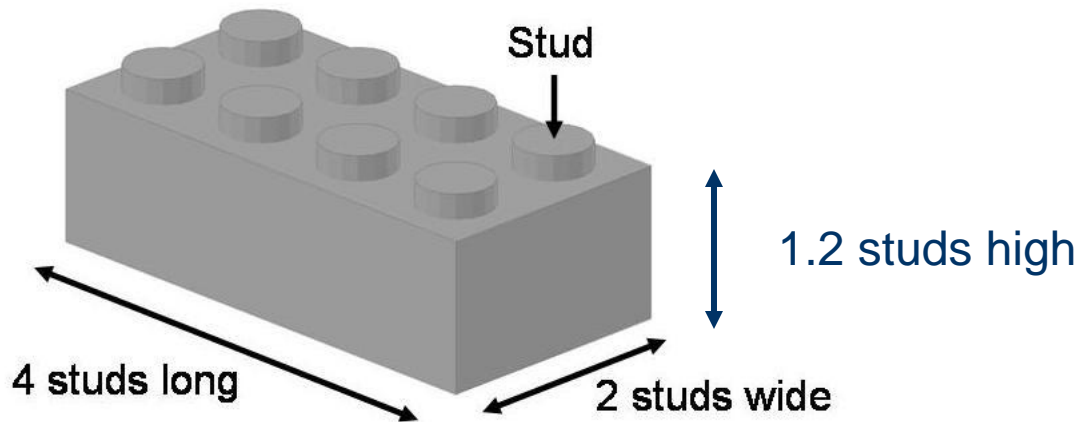
# Essential Terminology

- Driver – gear with applied force
- Follower – gear doing useful work
- Idler – gear turned by driver & turns follower
- Gear Train – many gears in a row
- Geared Up – large driver, small follower to speed gear train up.
- Geared Down – small driver, large follower to increase torque (turning force)
- Compound gears – combination of gears and axles where one axle has 2 gears often of different sizes.

# Basic Gear Properties

- When 2 gears mesh, driver makes follower turn in opposite direction
- Need odd number of idler gears to make driver and follower turn in same direction.
- Need 0 or even number of idlers to make driver and follower turn in opposite direction
- When large driver turns small follower, its called gearing up and speeds up gear train
- When small driver turns large follower, its called gearing down and increases torque (turning force).

# Basic Brick Geometry

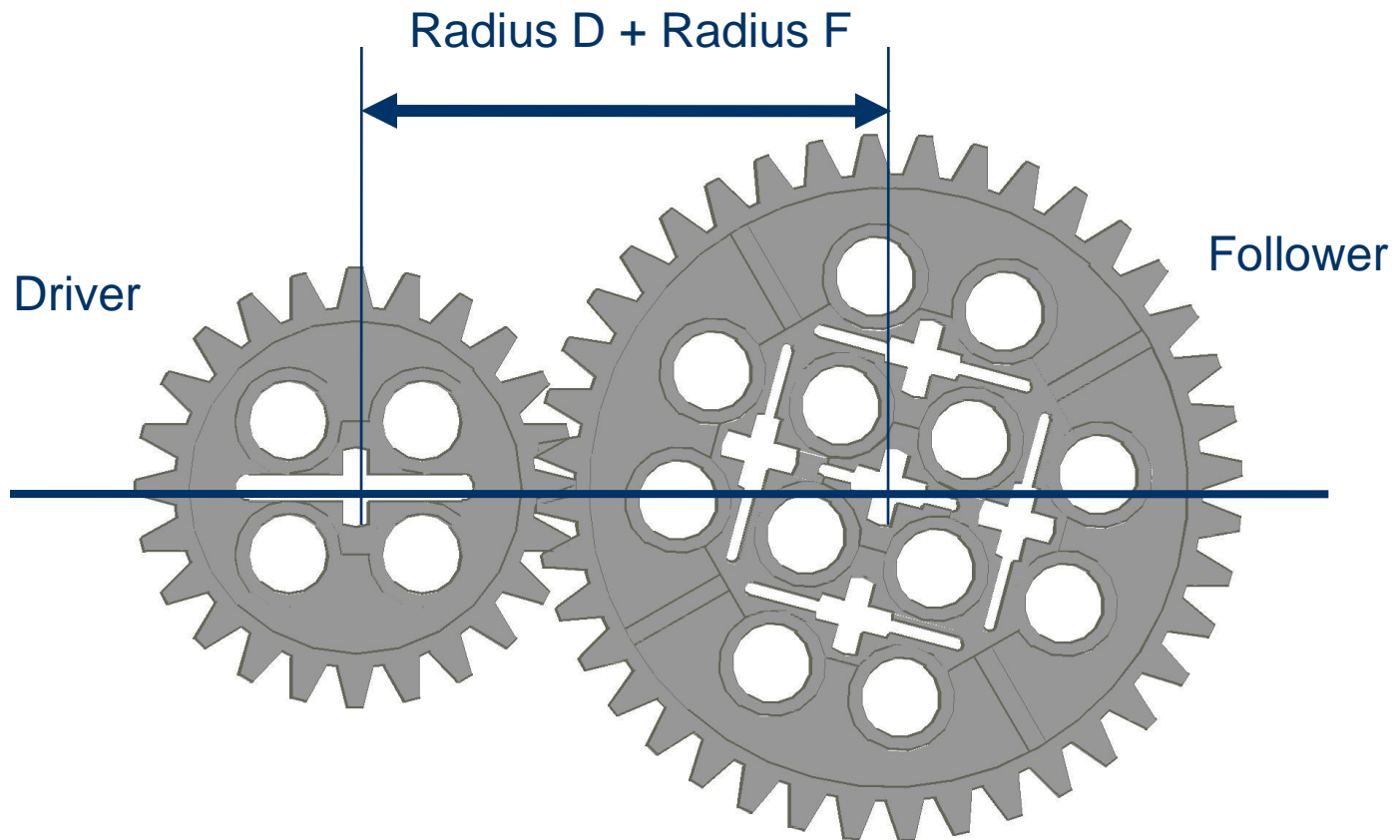


Brick/Beam = 3 Plates

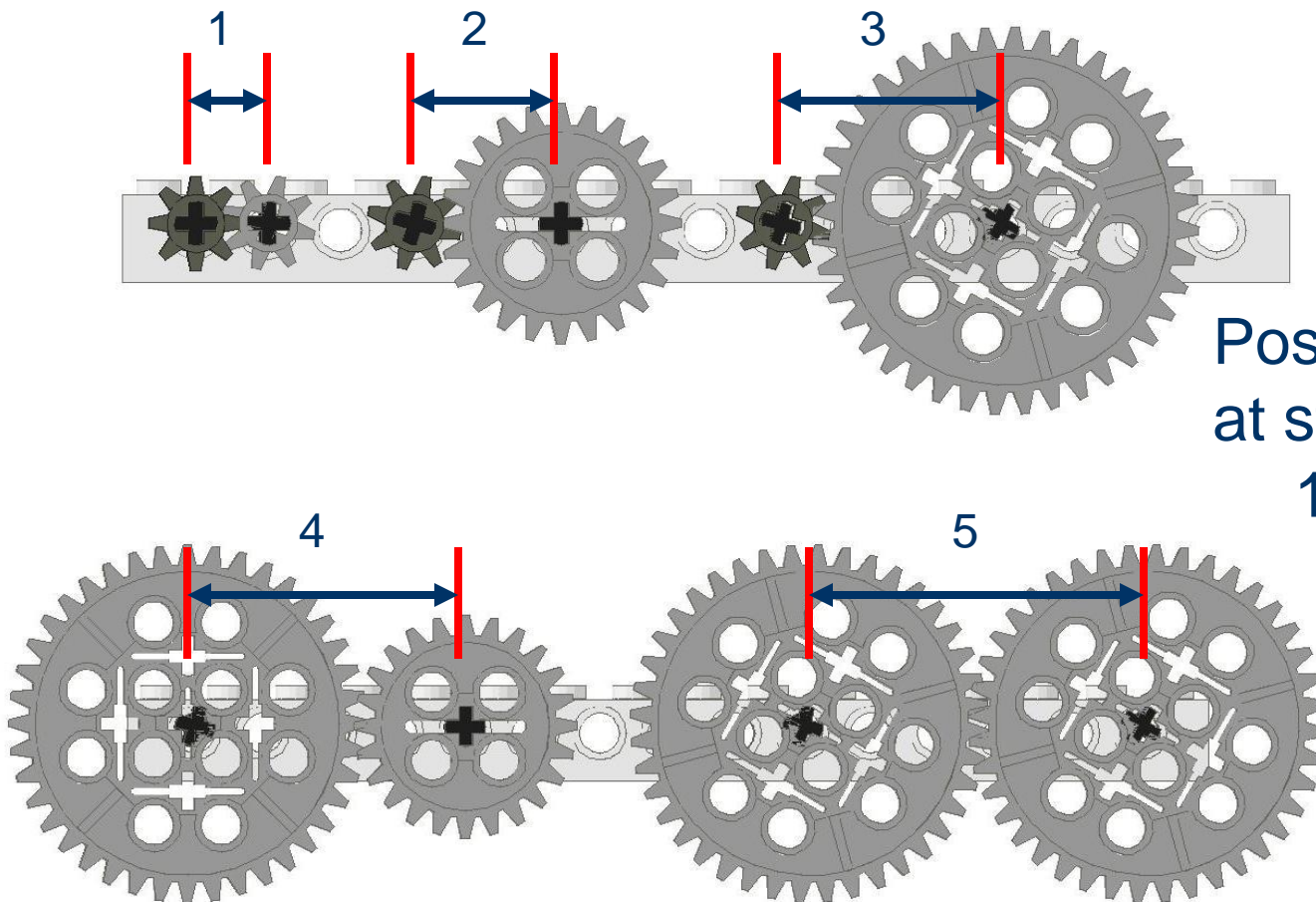
One plate is  $\frac{1.2}{3} = 0.4$  studs high

So each 5 plates will be 2 studs high ( $0.4 \times 5$ )

# Gear Geometry

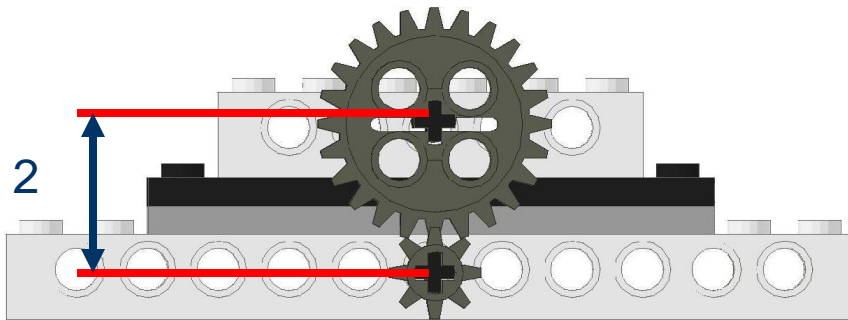


# Gears (Spur) Meshing Horizontally

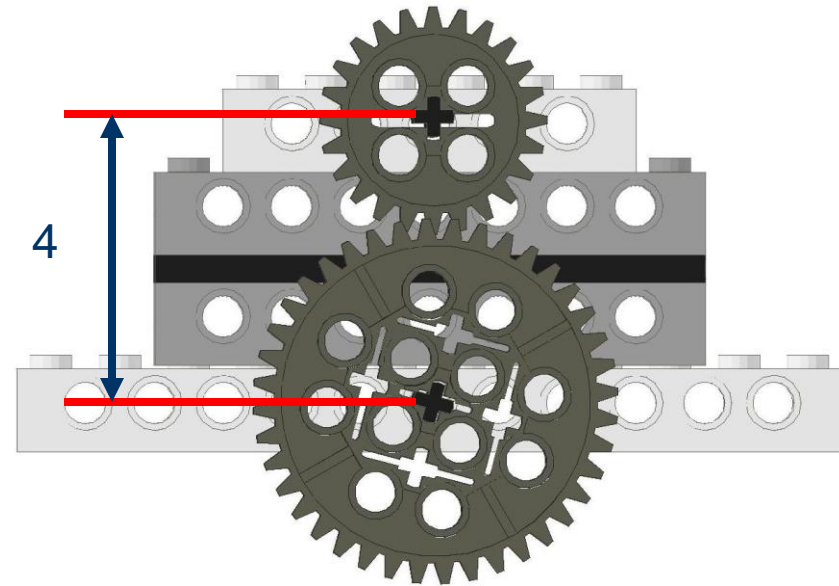


Possible to mesh  
at stud lengths of  
1 through 5

# Gears (Spur) Meshing Vertically



Using 24 tooth and 8 tooth  
at distance of 2 stud lengths



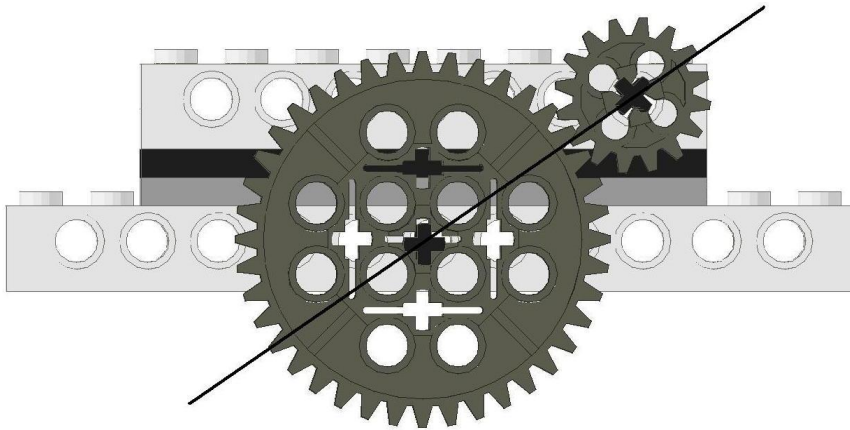
Using 24 tooth and 40 tooth  
at distance of 4 stud lengths

Mesh at even stud lengths for best results

# What happens with improper mesh?

- When 2 gears are meshed, there is a certain amount of built in “play” between them called backlash.
- When 2 gears are not meshed properly i.e. within specification you get too much backlash called **slop** OR too little backlash and they are jammed together and this creates **friction**.

# Gears (Spur) Meshing Diagonally

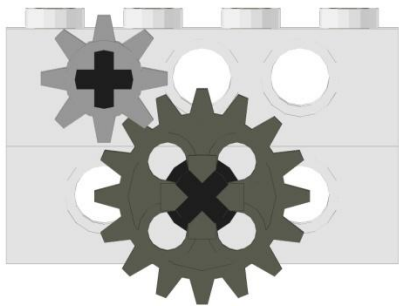


Slop or friction typically occurs when you make gears mesh diagonally

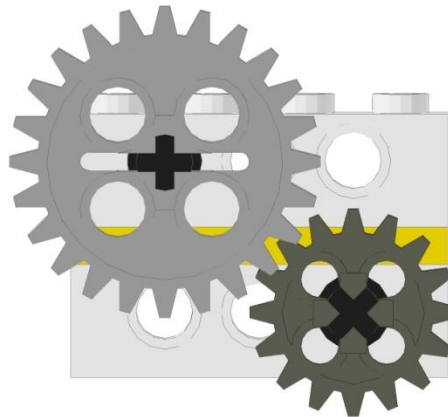
## Some Schools of Thought

1. Don't do it as it makes gears out of specification and something may go wrong e.g. gear teeth skipping
2. Do it as it gives you more creativity in meshing gears in different configurations.
3. Do it but within some tolerance e.g. under 1%

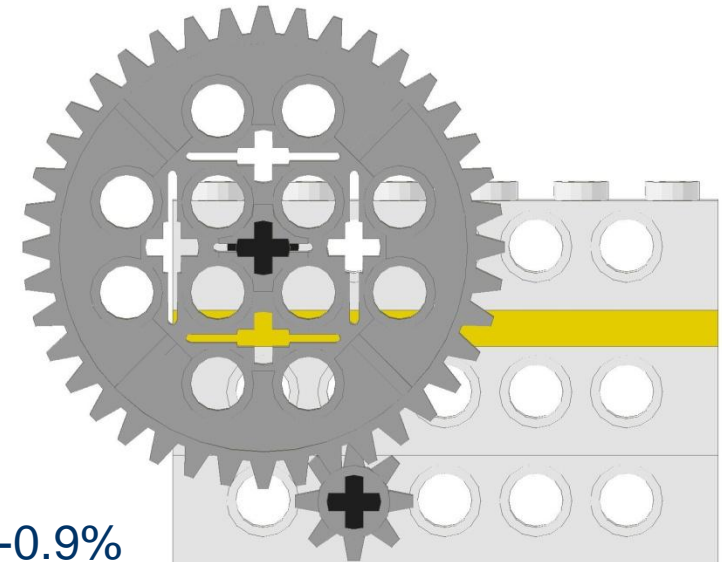
# Gear Guide in FLL Manual pg 49



4.1%



2.4%



-0.9%

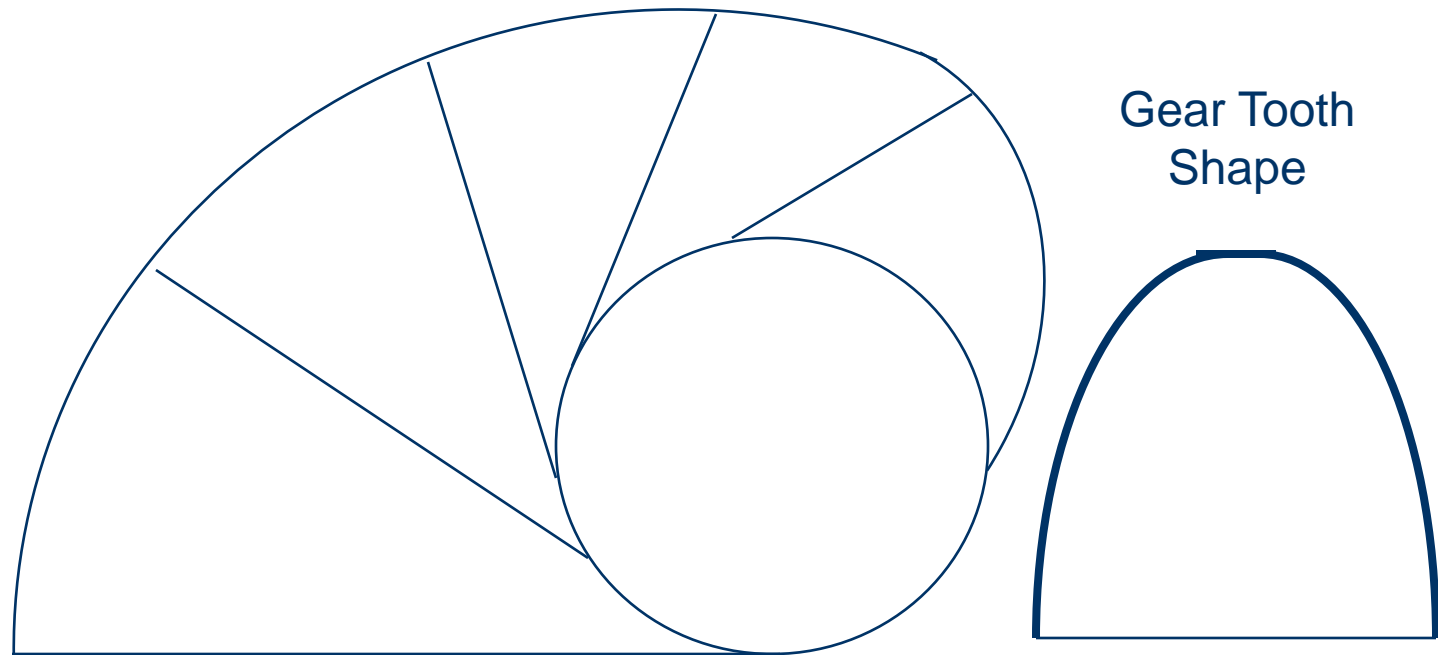
<u>Vert</u>	<u>SqVert</u>	<u>Hori</u>	<u>SqHori</u>	<u>AddSqs</u>	<u>Dist Bet Holes</u>	<u>RadTop</u>	<u>RadBott</u>	<u>Dist Ctrs</u>	<u>Diff</u>	<u>Percent</u>
1.2	1.44	1	1	2.44	1.56	0.5	1	1.5	0.0620	4.1
1.6	2.56	2	4	6.56	2.56	1.5	1	2.5	0.0612	2.4
2.8	7.84	1	1	8.84	2.97	2.5	0.5	3	-0.0268	-0.9
2.8	7.84	1	1	8.84	2.97	1.5	1.5	3	-0.0268	-0.9

# What is the best type of gear teeth?

- Gears need to have teeth that mesh properly otherwise they will not work.
- Best is a curve on the teeth that provides for constant velocity when gear turning
- Involute curves modeled on the teeth provides this advantage and is the basis for most modern gears.

# Gear Tooth Geometry -2

The involute curve can be generated by wrapping a string around a circle.



# Gear Ratio

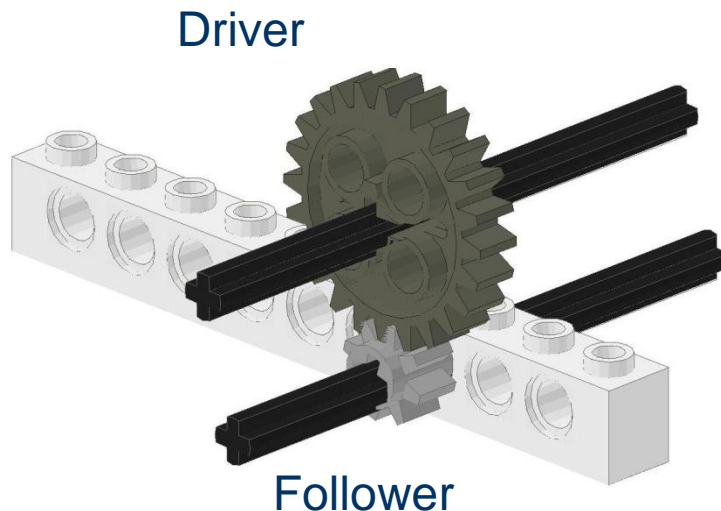
- In order to determine what a gear will do for us, we must quantify it.
- Best measure is the gear ratio.
- Gear Ratio =  $\frac{\text{number of teeth in follower}}{\text{number of teeth in driver}}$
- G.R. =  $F_t / D_t$  e.g.  $\frac{1}{3}$  or 1:3 (read as 1 to 3)
- Interpret above as one turn of driver will turn the follower 3 times.

# Gear Analysis

- To analyze any gear train you need to:
  1. Locate the driver gear (see force applied)
  2. Locate the follower gear (see where useful work done)
  3. Figure out if it is geared up or geared down (big circle turning small circle – geared up)
  4. Calculate the Gear Ratio using  $F_t/D_t$ . Use the following 3 rules for gear ratio calculation.

# Rule 1 – Pair up gears

- In the case of 2 gears, it is easy. The driver is the one driven by the motor or applied force. The follower is the one doing work.



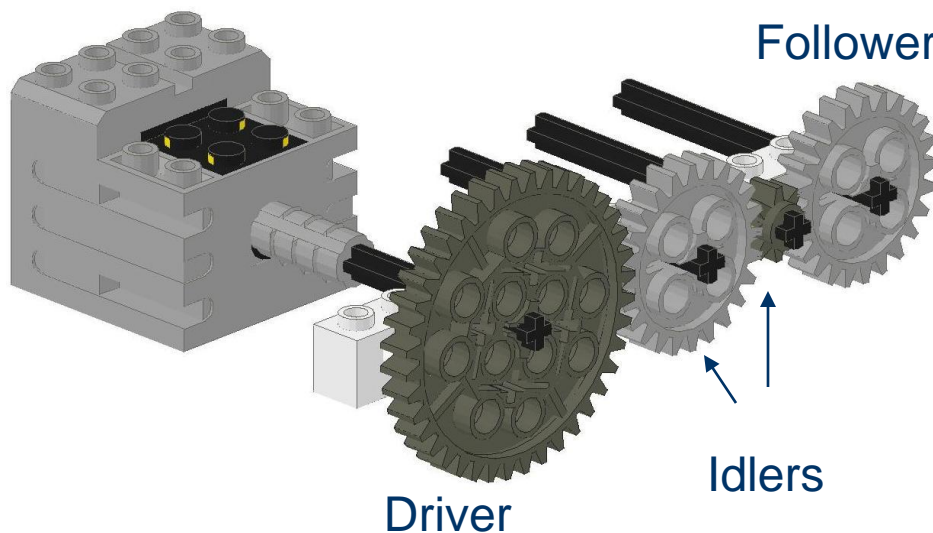
$$\text{Gear Ratio} = \frac{8}{24}$$

$$= \frac{1}{3}$$

One turn of the 24 tooth will turn the 8 tooth 3 times.

## Rule 2 - Long Gear Trains

- For many gears on different axles, driver is one connected to applied force, follower is the last one in the gear train. All others idlers.

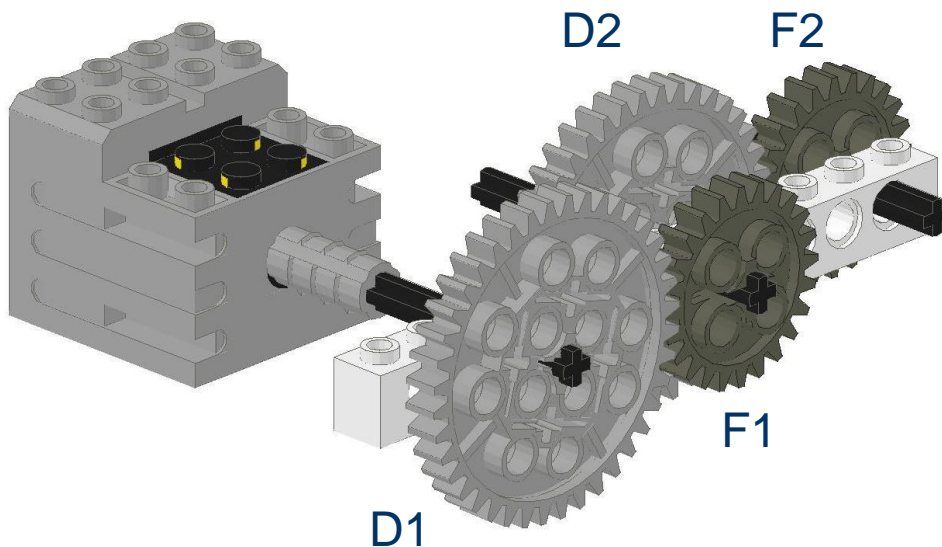


$$\text{Gear Ratio} = \frac{24}{40} \\ = \frac{3}{5}$$

3 turns of the 40 tooth will turn the 24 tooth 5 times.

# Rule 3 – Compound Gears

- Pair up as many drivers and followers and label them D1, F1, D2, F2, etc. as needed. Note every time you follow an axle and it has a second gear attached, start a new driver. Multiply the gear ratios of all pairs of driver-follower.



$$\begin{aligned} \text{Gear Ratio} &= \frac{24}{40} \times \frac{24}{40} \\ &= \frac{3}{5} \times \frac{3}{5} \\ &= \frac{9}{25} \end{aligned}$$

## Possible Gear Configuration Pairs other than 1:1 gear ratios

- 24t & 40t spur (or 12t & 20t dbl bevel) gives 3:5 or 5:3
- 24t & 8t spur gives 1:3 or 3:1
- Worm & 8t spur gives 9:1
- Worm & 24t spur gives 24:1
- Worm & 40t spur gives 40:1
- 20t & 36t dbl bevel at 90° gives 5:9 or 9:5

# Anecdotes to Spice Up Lessons

- South Pointing Chariot – differential gear
- Antikythera Mechanism – 32 gears in box that can predict movement of planetary objects like sun, moon, earth, zodiac, etc.

# Real World Gear Types

- Spur gears
- Helical gears
- Bevel gears
- Differential gears
- Worm gears
- Planetary Gears
- Harmonic Drive gears