MATRIX | FUNDAMENTAL MECHANICS

Mechanisms Plus

MATRIX

CP3085

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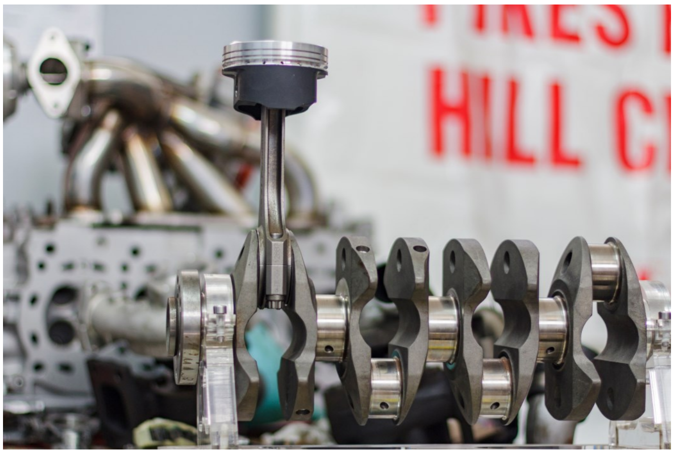
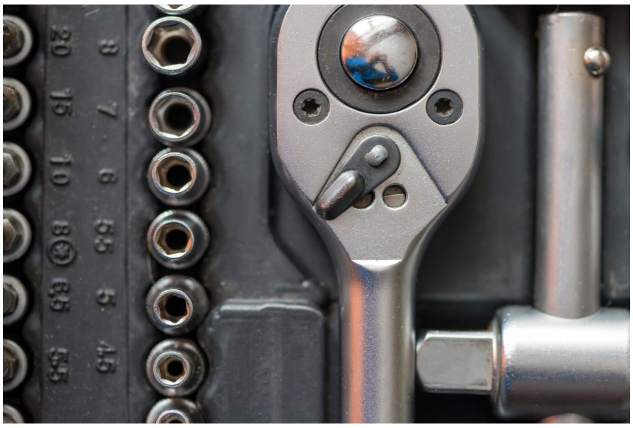
Contents

Chapter 1
Mechanisms

A mechanism consists of interconnected machine parts joined together by moveable joints. They work together to modify input forces and motion to create the desired output forces and motion.





Using a mechanism can multiply the force we apply, so that we no longer need to rely on muscle power alone.

They usually contain moving components, such as:

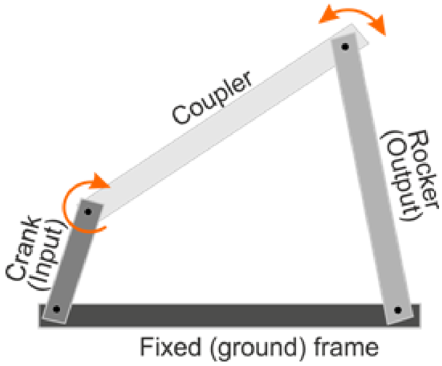
- gears or gear trains;
- belt and chain drives;
- cams and cam followers;
- friction devices, such as brakes and clutches;
- and structural components that support the mechanism.

Worksheet 1
Four-bar linkage

The four-bar linkage plays a central role in systems from car suspensions to robotic arms.

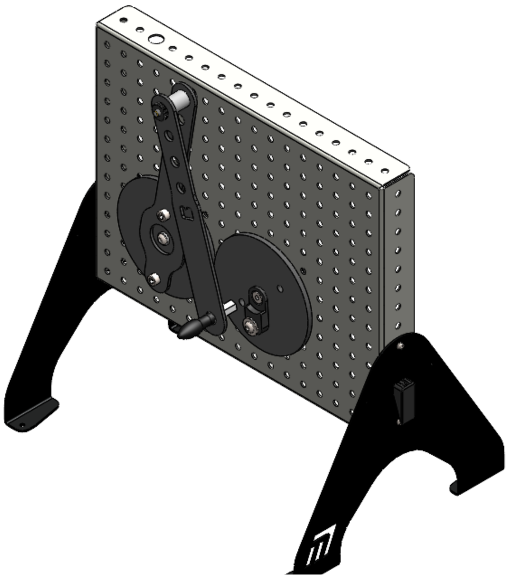
The ground link provides the reference plane for the system. Other links are known as the crank (the shortest link,) the rocker and the coupler, which connects these together.

These links are connected together either by pin (revolute) joints or by prismatic (slider) joints.
(Link names may vary from source to source.)

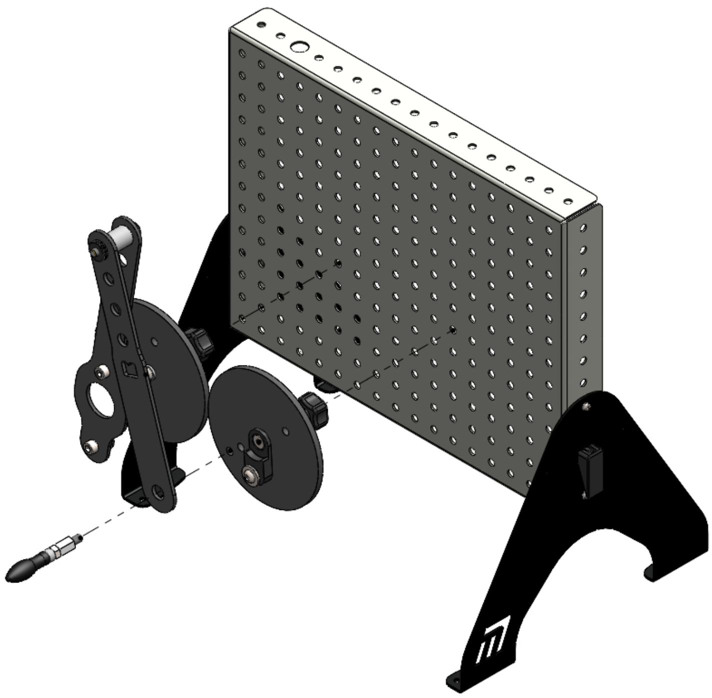


Over to you:

- Set up the system shown in the diagram.

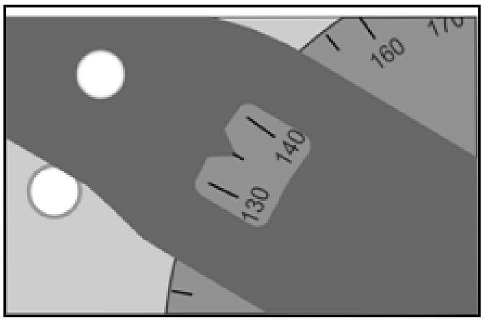


- The centre of the crank disc should be in the same horizontal row as the output disc, with six empty vertical rows between the screws used to fasten them to the baseboard.
- Fasten the linkages to the discs using the holes located 30mm from the centre of the disc.



Worksheet 1
Four-bar linkage

Over to you.....



- Turn the right-hand disc until the indicator on the linkage points to135°. This ensures that the readings on the left-hand disc (output link) will be positive values, making plotting the graph easier.
- Slowly rotate the right-hand disc in an anticlockwise direction. As you do so, notice how the output moves .
- Now, rotate the right-hand disc anticlockwise in 30^0 steps. Each time, note the reading on the left-hand disc.
- Record all readings in the table in the Student Handout.

So what:

- Use your results to plot a graph of output angular displacement against input angular displacement, to illustrate the relationship between them.
- Change the arrangement of the four-bar linkage by altering the lengths of the linkages. Repeat the same measurement procedure and plot the results on the same graph as before, to allow easy comparison of the behaviour of the two configurations. In the Student Handout, comment on this comparison.

Challenge:

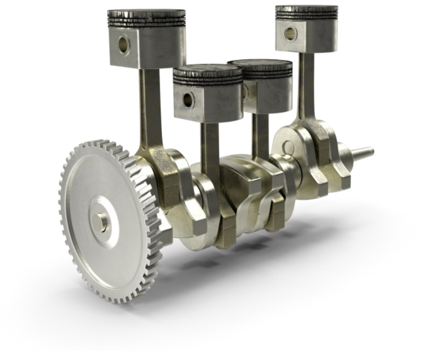
The pedal cycle:

- Explain how the four-bar linkage arrangement applies to a cyclist pedalling a bicycle.

Worksheet 2

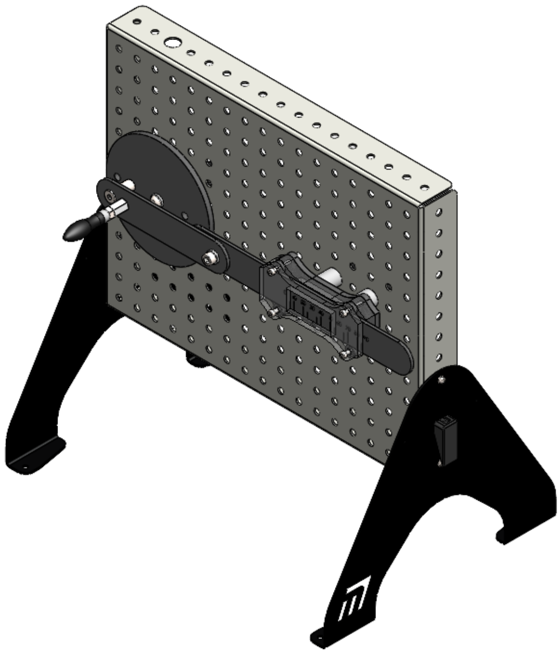
Crank and slider

In an internal combustion engine, when petrol burns in the cylinder head, the expanding gases force the piston down inside the cylinder. This linear motion must be converted into circular motion, to rotate the car wheels. This conversion is carried out by the mechanism studied here, the crank and slider.

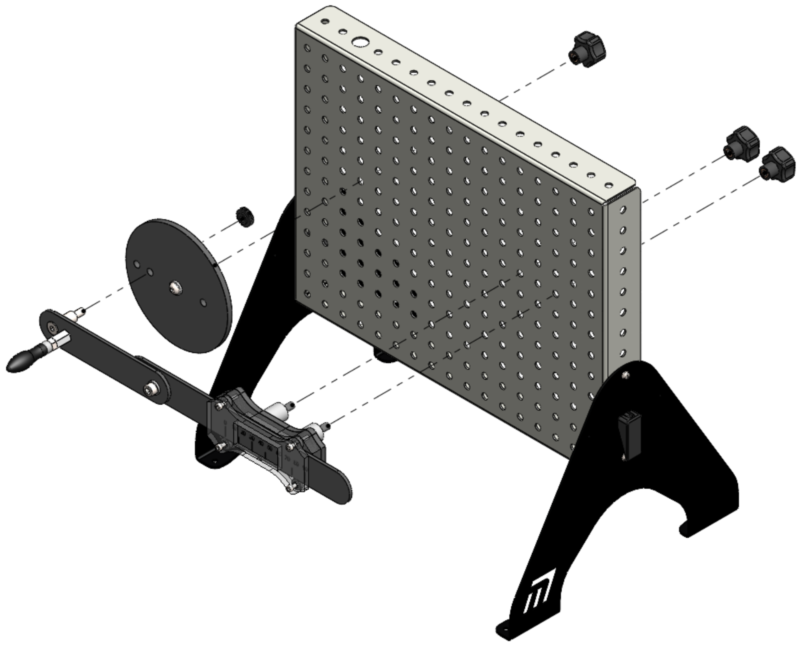


Over to you:

- Set up the crank and slider system shown in the diagram.



- The centre of the crank should be in the same horizontal row as the slider block, with nine empty vertical rows between the screws used to fasten them to the baseboard.
- Initially, fasten the linkage assembly to the crank wheel using the hole located 30mm from the centre of the disc.



Worksheet 2
Crank and slider

Over to you.....

- Check that the slider moves smoothly inside the slider block when you rotate the crank.
- Rotate the crank until the zero on the slider sits beneath the pointer in the centre of the slider block window, as shown in the image.

- Rotate the crank anticlockwise in 30^0 steps. Each time, note the reading on the linear mm scale on the slider.
- Record all readings in the table in the Student Handout.

So what:

- Use your results to plot a graph of linear displacement against crank angle, to illustrate the motion of the slider inside the block.
- What is:
    - the maximum linear displacement of the slider;
    - the crank angle at which this occurs?
- Record your answers in the Student Handout.

Challenges:

1. Slider velocity:

- Notice what happens to the velocity of the slider when you rotate the crank at a steady rate. (Remember - velocity is a vector quantity and so concerns direction as well as speed!)

  In the Student Handout, comment on what you see.

2. Crank linkage position:

- Repeat the investigation but this time with the linkage assembly fastened to the crank wheel using the hole located 40mm from the centre of the disc.
- Compare the two sets of readings. What effect does the change have on the behaviour of the system? Write your comments in the Student Handout.

Worksheet 3

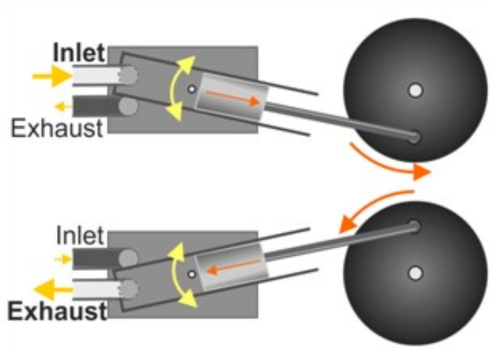
Worksheet 3

Oscillating cylinder

An early form of steam engine used the oscillating cylinder principle.

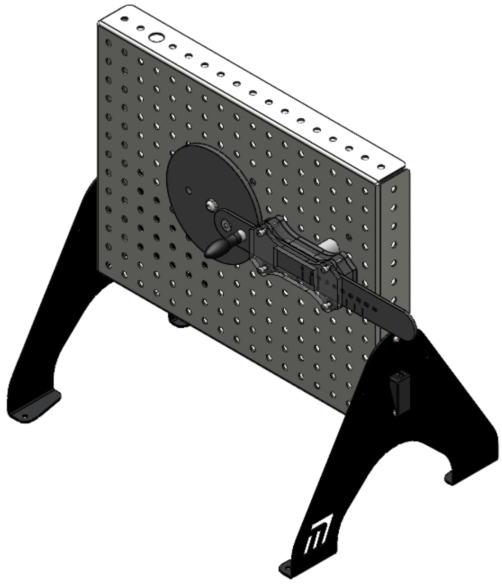
As the cylinder rocked on its axis, it repeatedly covered and uncovered the inlet and exhaust ports.

As a result, steam repeatedly entered the cylinder, forced the piston down it, turned the crank and then allowed the steam to escape through the exhaust port.

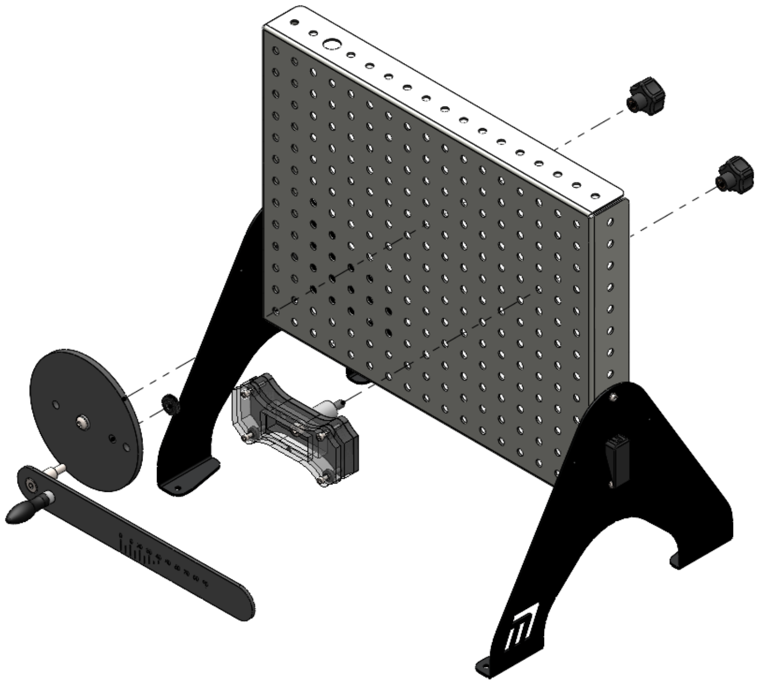


Over to you:

- The system is similar to the crank and slider, used in worksheet 1. There, however, the slider block was fixed in position. Here it is allowed to pivot on a trunnion so that it remains in line with the linking rod. Set up the oscillating cylinder system shown in the diagram.



- Once again, the centre of the crank should be in the same horizontal row as centre of the slider block with six empty vertical rows between the screws used to fasten them to the baseboard.
- Fasten the linkage assembly to the crank wheel using the hole located 30mm from the centre of the disc.
- Check that the slider moves smoothly inside the slider block when you rotate the crank.



Worksheet 3
Oscillating cylinder

Over to you.....

- Rotate the crank until the reading on the slider sits at its minimum value.
- Rotate the crank anticlockwise in 30^0 steps, as before and each time, note the reading on the linear mm scale on the slider.
- Record all readings in the table in the Student Handout.

So what:

- To help to visualise the motion of the slider inside the slider block, plot a graph of linear displacement against crank angle.
- What is:
    - the maximum linear displacement of the slider;
    - the crank angle at which this occurs?
- Record your answers in the Student Handout.

Challenge:

What would be the effect on the motion of using:

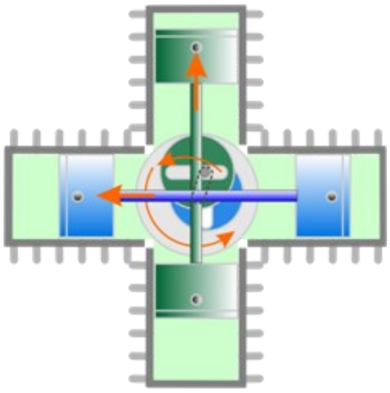
- the 40mm hole on the crank disc;
- a longer slider?

Give your answers to these questions In the Student Handout.

Worksheet 4
Scotch yoke

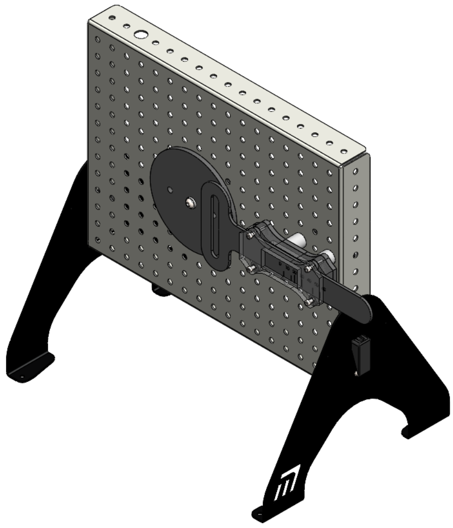
Another way to convert between linear and rotary motion, the Scotch Yoke mechanism uses a pin, attached to the crank, moving inside a slot attached to the slider.

The Bourke engine, an internal combustion engine, used this mechanism instead of a crankshaft. Its benefits included fewer moving parts . However, the sliding pin, rubbing against the slot, caused rapid wear leading to the need for regular maintenance.

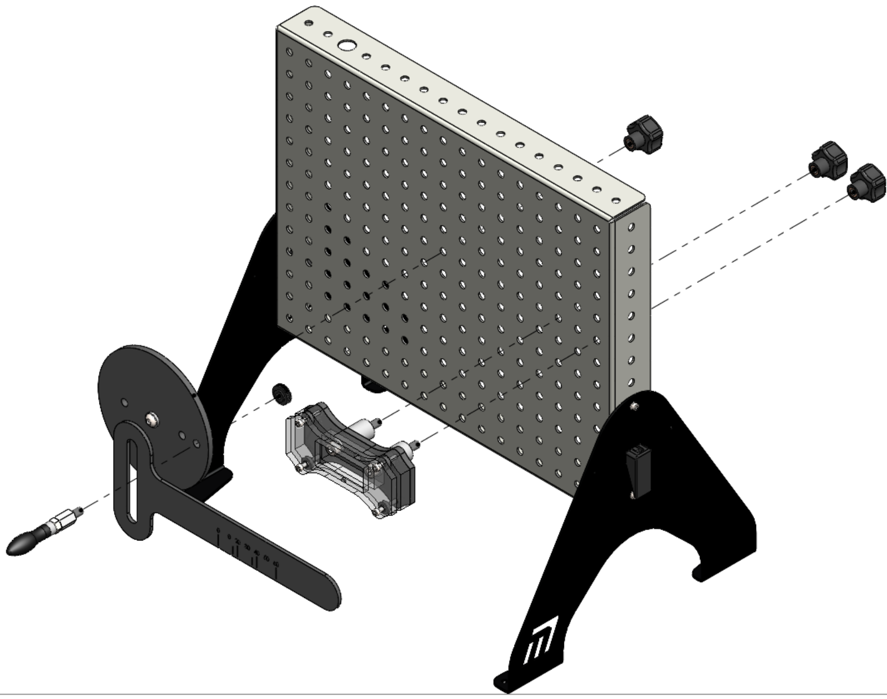


Over to you:

- This is another variation on the crank and slider, used in worksheet 1. The slider block is fixed, unlike that in the oscillating cylinder mechanism. The slider is driven by a pin, attached to the crank, sliding inside a vertical slot. Set up the system as shown in the diagram.



- This time, the centre of the crank should be in the same horizontal row as centre of the slider block with four empty vertical rows between them.
- Fasten the linkage assembly to the crank wheel using the hole located 30mm from the centre of the disc.
- Check that the slider moves smoothly inside the slider block when you rotate the crank.



Worksheet 4
Scotch yoke

Over to you.....

- Turn the crank disc in an anticlockwise direction and notice that the slider moves faster in one direction than in the other.
- Rotate the crank disc until the reading on the slider sits at zero on the slider scale.
- Rotate the crank in 30^0 steps, as before and each time, note the reading on the linear mm scale on the slider.
- Record all readings in the table in the Student Handout.

So what:

- To visualise the motion of the slider, plot a graph of linear displacement against crank angle.
- Once again, use your graph to determine:
    - the maximum linear displacement of the slider;
    - the crank angle at which this occurs?
- Record your answers in the Student Handout.

Challenge:

- Draw up a short report summarising the advantages and disadvantages of using this mechanism instead of a crankshaft in a 4-stroke internal combustion engine.

Give your answers to these questions In the Student Handout.

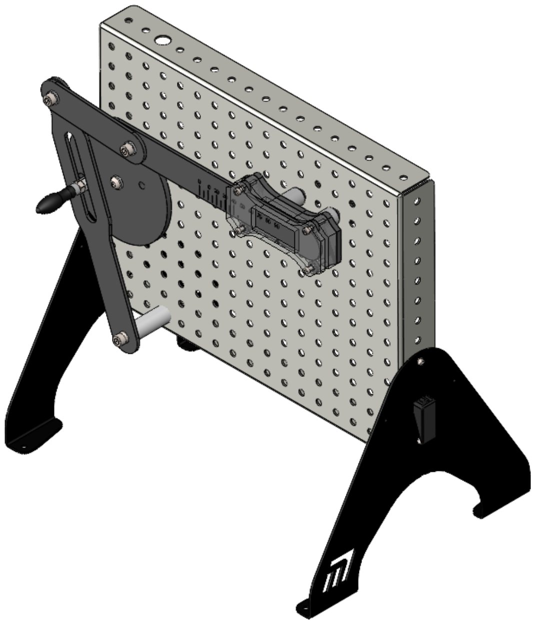
Worksheet 5
Slotted link quick return

In a quick return mechanism, the slider returns in a shorter time, even though the crank is turning at a constant speed.

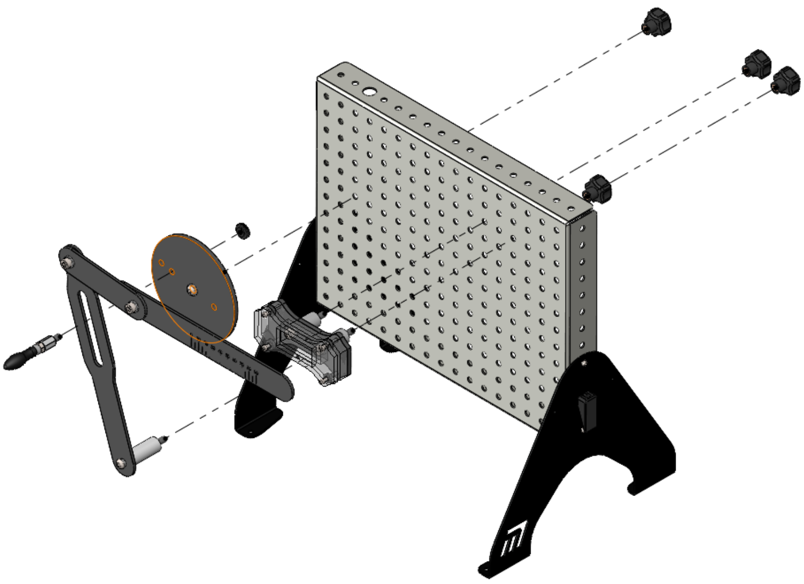
This is used in machine tools such as shaping machines. The 'quick return' mechanism allows the machine to return to the starting position rapidly after performing its task, to prepare for the next one, thus reducing the cycle time.

Over to you:

- This is another variation on the crank and slider. The slider block is fixed. The slider is driven by a pin, attached to the crank, sliding inside a slot. The other end of this slotted link is fixed to the baseboard.



- Set up the system as shown in the diagram.
- From the centre disk attach the guide block 10 hole to the right and 3 holes up.
- Attach the bottom pivot of the linkage 7 holes down and 1 hole to the right.
- Fasten the linkage assembly to the crank wheel using the hole located 30mm from the centre of the disc.
- Fasten the bottom of the slotted link to the baseboard as shown.
- Check that the slider moves smoothly inside the slider block when you rotate the crank.



Worksheet 5
Slotted link quick return

Over to you.....

- Rotate the crank until the reading on the slider sits at zero on the slider scale.
- Place a magnetic marker to indicate the zero on the angle scale around the crank disc in this position.
- Rotate the crank in 30^0 steps, as before and each time, note the reading on the linear mm scale on the slider.
- Record all readings in the table in the Student Handout.

So what:

- To help to visualise the motion of the slider inside the slider block, plot a graph of linear displacement against crank angle.
- Once again, use your graph to determine:
    - the change in angle needed to move the slider from 0^0 to maximum displacement on its outward stroke;
    - the change in angle needed to move the slider back from maximum displacement to 0^0 on its return stroke.
- Record your answers in the Student Handout.

Challenge:

- The ‘quick return’ effect is governed by the distance between the centre of the crank and slider pin, (currently 30mm) compared to the distance between the centre of the crank and slider link pivot (currently 140mm).
- Investigate the effect of changing these distances on the ‘quick return’ effect.
- Report on your investigation and its findings in the Student Handout.

Worksheet 6
Whitworth quick return

Over to you.....

- Rotate the crank until the slider sits at zero in the slider block window.
- Rotate the crank in 30^0 steps, as before and each time, note the reading on the linear mm scale on the slider.
- Record all readings in the table in the Student Handout.

So what:

- To visualise the motion of the slider inside the slider block, plot a graph of linear displacement against crank angle.
- Use your graph to determine:
  - the change in angle needed to move the slider from 0^0 to maximum displacement on its outward stroke;
  - the change in angle needed to move the slider back from maximum displacement to 0^0 on its return stroke.

Challenge:

- Once again, investigate the effect on the 'quick return' effect of changing the configuration of the system.
- Report on your investigation and its findings in the Student Handout.

Chapter 2
Additional Mechanisms

Earlier investigations looked at a range of devices based on mechanisms such as ‘Crank and Slider’ or ‘Slotted Linkage Return Mechanisms’.

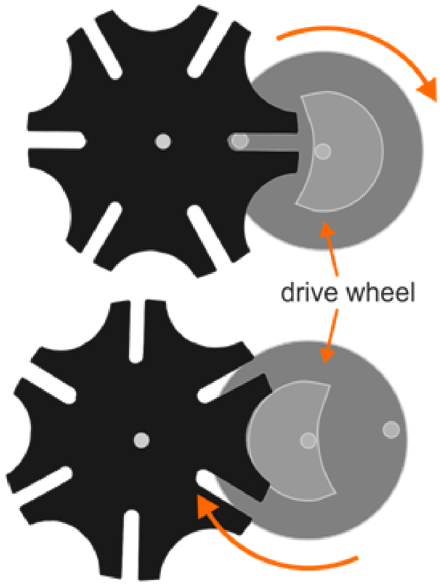
Here we add two more, the Geneva mechanism and the ratchet wheel.

The Geneva mechanism consists of a circular drive wheel and a driven wheel having a number of slots and circular indentations.

A crank pin on the drive wheel can locate in one of the slots and rotate the driven wheel until the next slot is in place.

In the meantime, the raised circular block on the drive disc interlocks with the adjacent indentation on the driven wheel and locks it in position between steps.

This behaviour is known as intermittent-indexed rotary motion, meaning that the drive wheel steps the driven wheel to new, set positions quickly and precisely.

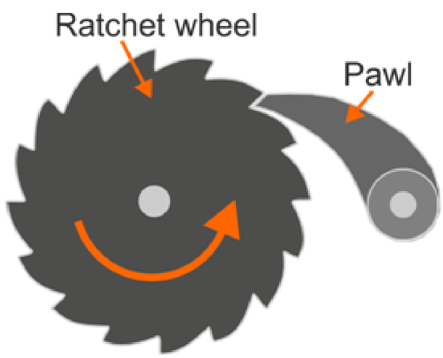


Geneva mechanism

A **ratchet** wheel allows continuous rotary motion in one direction only.

It consists of a toothed gear wheel and a spring-loaded finger called a *pawl* that engages the teeth.

With the wheel moving in the ‘forward’ direction, the pawl slides up and over the shallow sloped sides of the teeth. Should the direction of rotation try to reverse, the pawl hits the steeply sloped side of the first tooth and locks, preventing any further motion in that direction.



Ratchet

Worksheet 7
Geneva Mechanism

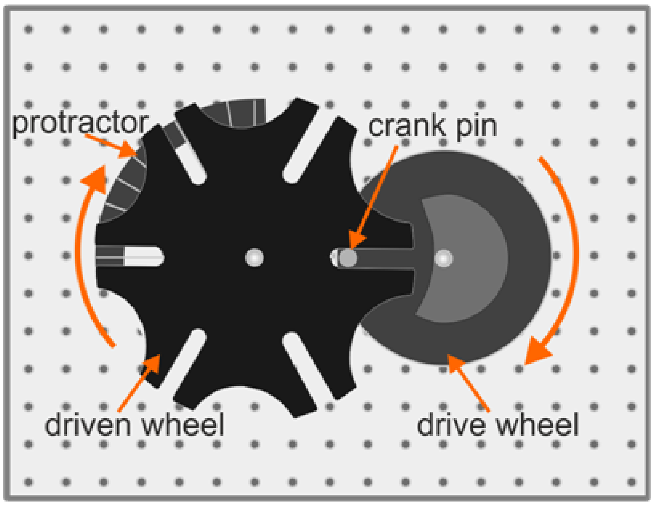
Film projectors and cameras can use a Geneva mechanism to move the film through the exposure gate. It briefly remains stationary in front of the lens before rapidly moving on to the next frame.

Other applications include use in mechanical watches, bank note counting machines and machine tools such as turret lathes, drills and CNC machines.

Over to you:

As the drive wheel rotates, the crank pin enters one of the slots in the driven wheel, thereby rotating it. As the drive wheel continues to rotate, the crank pin eventually disengages and the driven wheel becomes locked in position on the rotating drive wheel.

- Set up the system shown in the diagram.



- Rotate the drive wheel at a steady speed and observe the behaviour of the driven wheel.

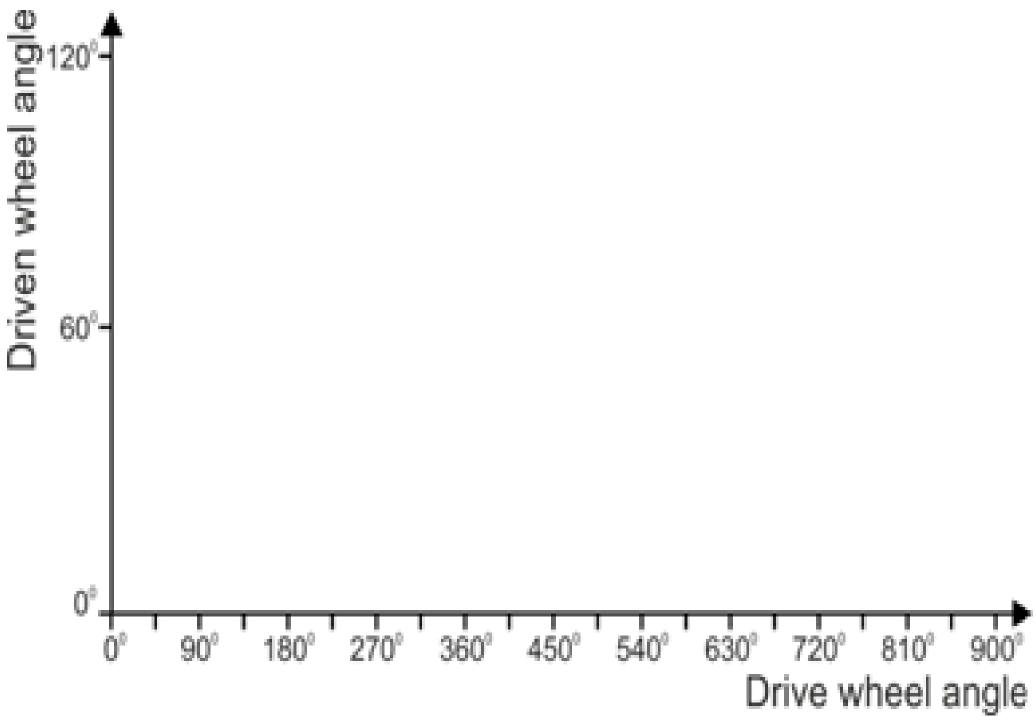
Worksheet 7
Geneva Mechanism

Over to you.....

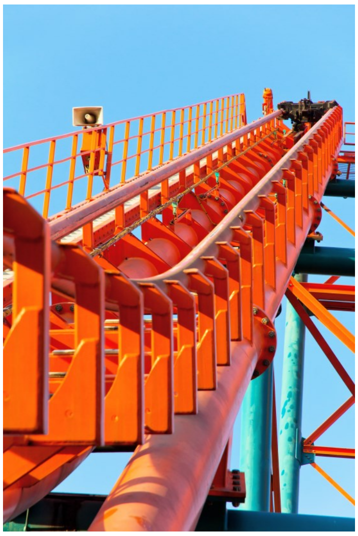
- Perform the following actions and answer the questions about the resulting behaviour of the driven wheel in the Student Handout:
    - Starting in the position shown in the diagram, rotate the drive wheel through 360^0. What angle does the driven wheel turn through as a result?
    - Now rotate the drive wheel in 45^0 steps round to 315^0. Describe the behaviour of the driven wheel during this action.

So what:

- In the Student Handout, sketch a graph on axes like those shown below to illustrate how the position of the the driven wheel changes as the drive wheel rotates.



Worksheet 8
Ratchet Mechanism



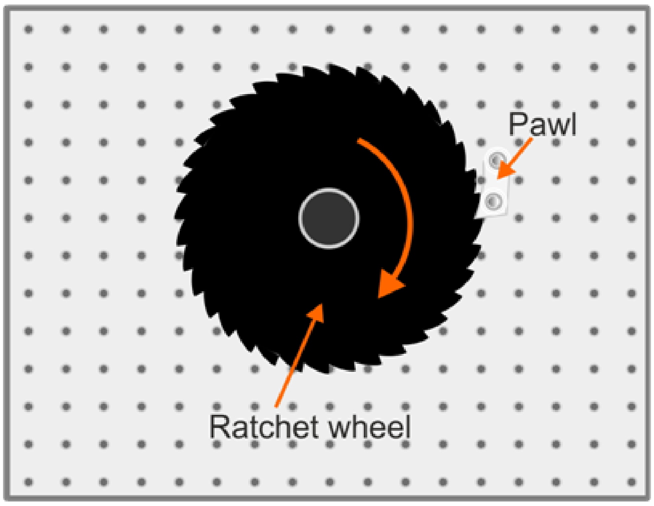
On most roller coasters, the cars can travel up the ‘lift hill’, but not down!

A motor-driven chain moves along a track beneath the roller coaster cars. As the chain ascends, it engages with a catch mechanism on the underside of the cars, lifting them gradually up the ‘lift hill’, essentially a linear ratchet.

Over to you:

This investigation explores the behaviour of a rotary ratchet mechanism.

- Set up the system shown in the diagram.



- Grip the ratchet wheel across its face and rotate it clockwise.
- Attempt to rotate it in the reverse direction (anti-clockwise).

  Notice how the pawl prevents rotation.

So what:

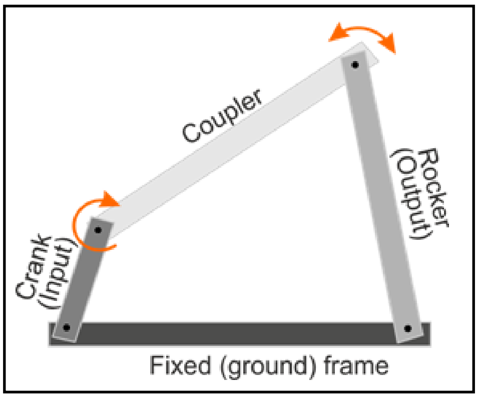
- In the Student Handout, answer the following:
    - Through how many degrees does the ratchet wheel turn between each complete ’click’ of the pawl?
    - What would be the effect of increasing the number of teeth on the motion of the wheel?
    - What factors affect the strength of the mechanism to resist backward motion?

Chapter 3
4 Bar Linkages

Bar linkages in the form of a lever and fulcrum, for example, are probably the first class of machines that humans ever employed.

A four-bar linkage, consisting of four bars connected in a loop by four joints has many functions, such as converting rotational motion to reciprocating motion and vice-versa.

It plays a central role in a wide range of systems from car suspensions to robotic arms.



The four links are known as:

- the **ground** link - provides the reference plane for the system;
- the **crank** (the shortest link,);
- the **rocker** and the **coupler**, which connects the other two together

These links are connected together either by **pin (revolute)** joints or by **prismatic (slider)** joints.

(Link names may vary from source to source.)

Grashof's theorem:

A fundamental theory for four-bar linkages, it was first developed to deal with mechanisms where all joints can rotate.

It states that:

- at least one link can rotate fully if **l** + **s** ≤ **p** + **q**;
- none of the links can rotate fully if **l** + **s** > **p** + **q**;

where:

s is the shortest link

l is the longest link

p and **q** are the remaining two links,

i.e. **l** > **p** ≥ **q** > **s**.

Chapter 3
4 Bar Linkages

Four-bar linkage systems can be described as having one degree of freedom, meaning that when one link is moved, the others can each move to only one, predictable, position.

The first series of investigations look at different versions of four-bar linkage systems:

1. the drag link;
2. the crank rocker;
3. the double rocker;
4. the parallelogram;
5. the Chebyshev linkage;
6. the Watt's linkage;
7. the Peaucellier-Lipkin linkage;
8. the Hart's Inversor;
9. the Robert's linkage;
10. the pantograph;
11. the Ackermann steering linkage.

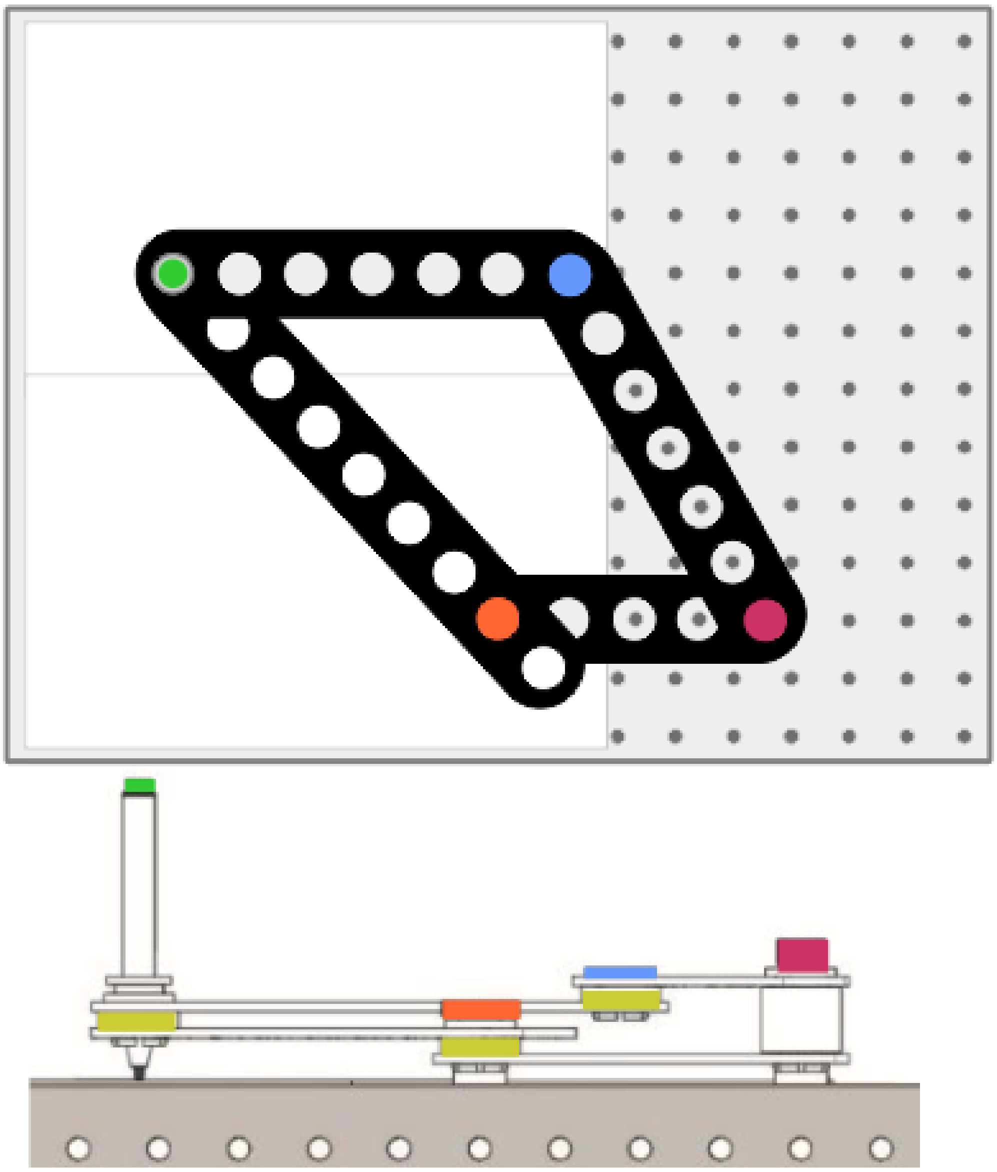
Over to you:

For each, use the information given in the diagrams on the following pages to build the systems. Then test them using the instructions that follow the diagrams.

Key to symbols used in the diagrams:

Plan	Elevation	Component
		Marker pen
		bolt
		bolt
		bolt
		Spacer - single depth
		Spacer - double depth

Worksheet 9
The drag link

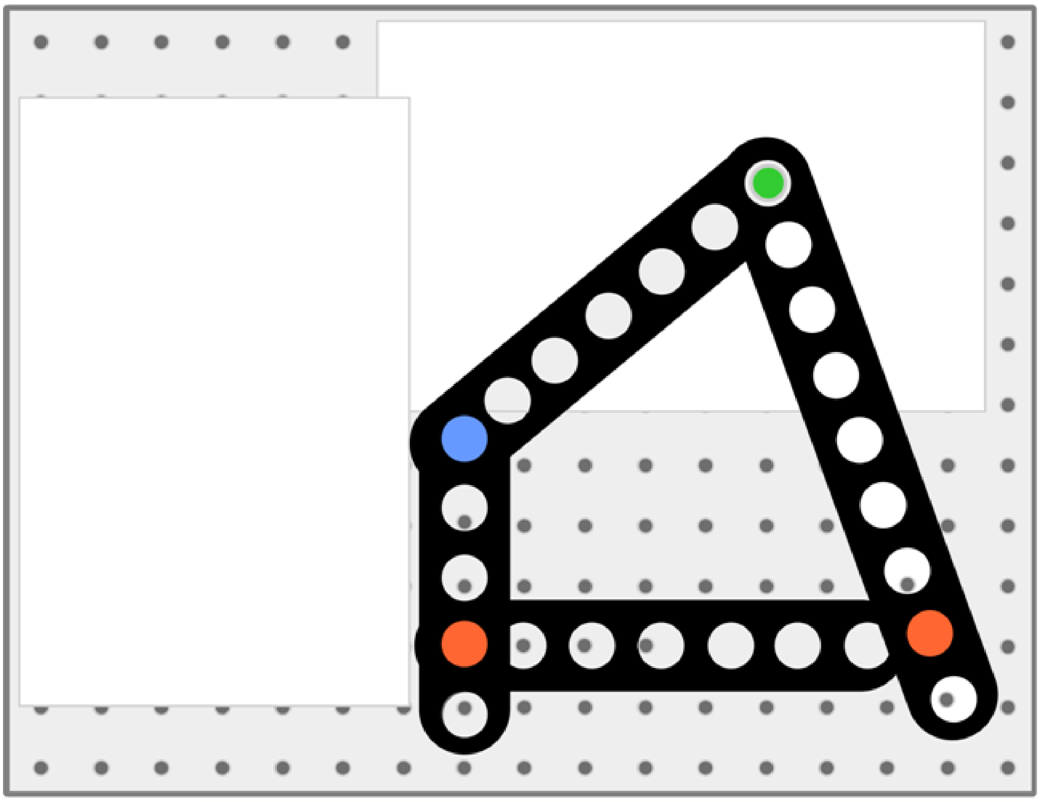


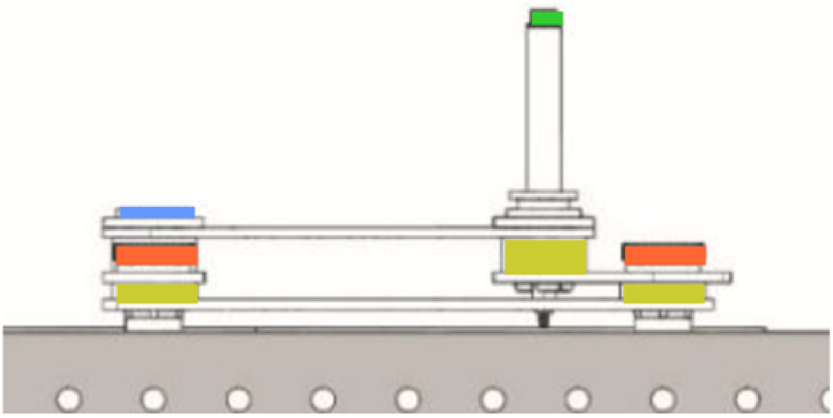
Over to you.....

- Place a marker pen in the centre hole of the five-hole link.
- Test the system by moving the linkages in a circular motion.
- Observe the resulting continuous rotational motion of the mechanism.
- Make an accurate sketch of this on the template provided in the Student Handout.

  The pen is shown as a green circle.

Worksheet 10
The crank rocker

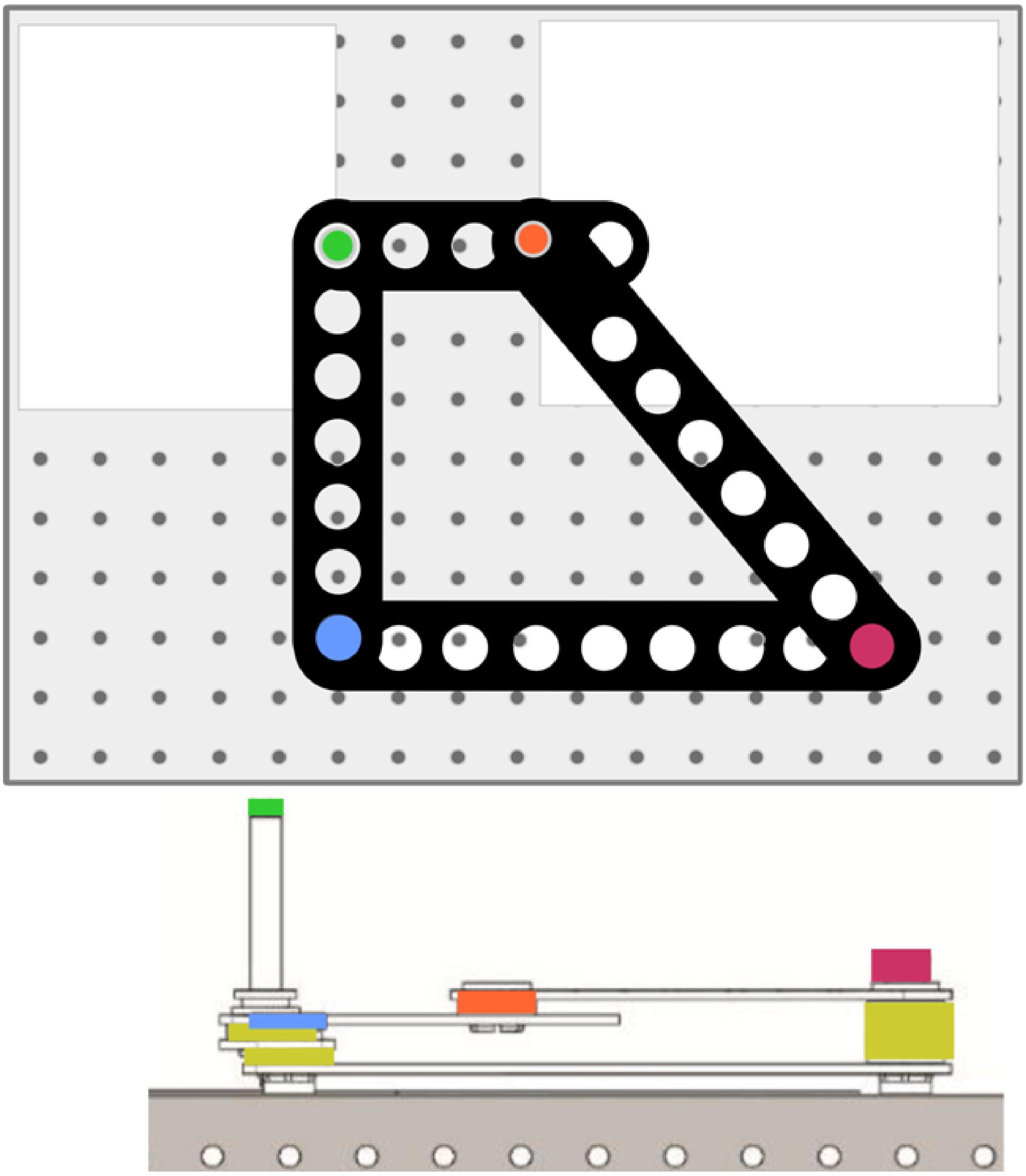




Over to you.....

- Test the system by rotating the smallest bar link in a circle.
- Observe the resulting motion of the mechanism.
- Make an accurate sketch of it on the template provided in the Student Handout.

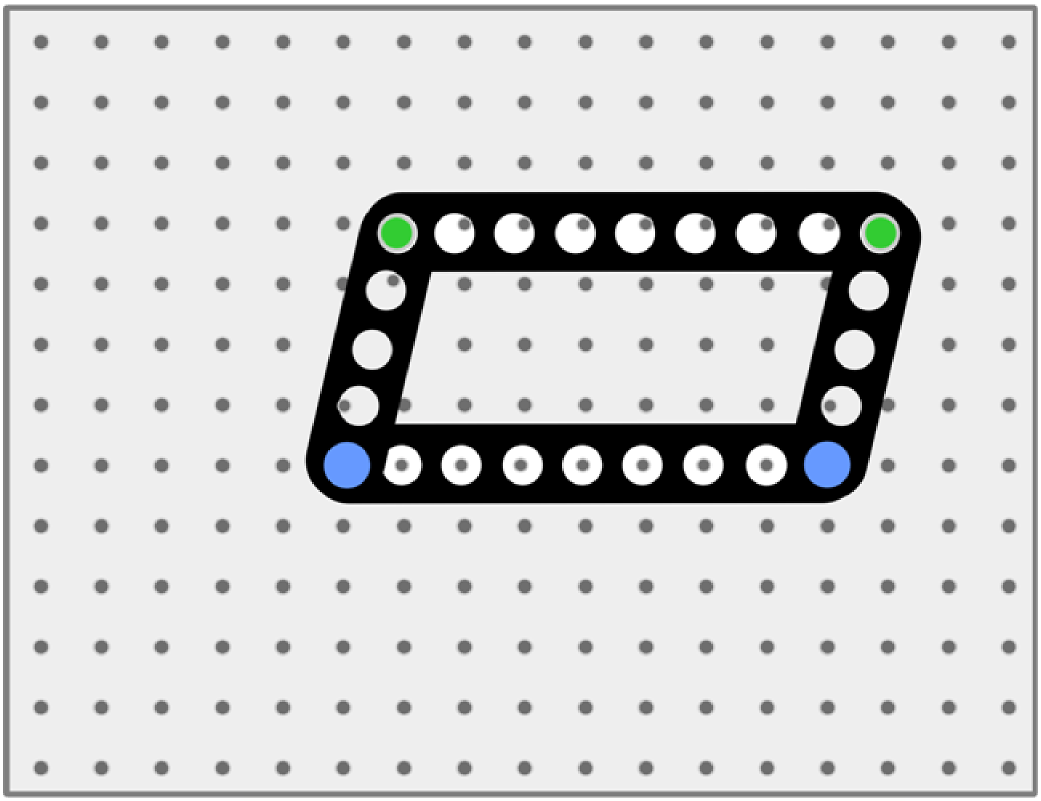
Worksheet 11
The double rocker

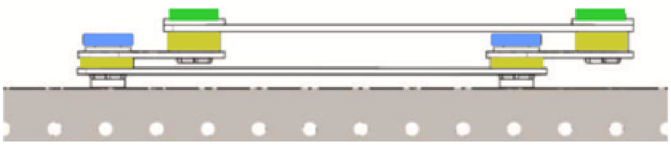


Over to you.....

- Test the system by rotating the five-hole link.
- Observe the resulting rocking motion of the double rocker linkage.
- Make an accurate sketch of it on the template provided in the Student Handout.

Worksheet 12
The parallelogram

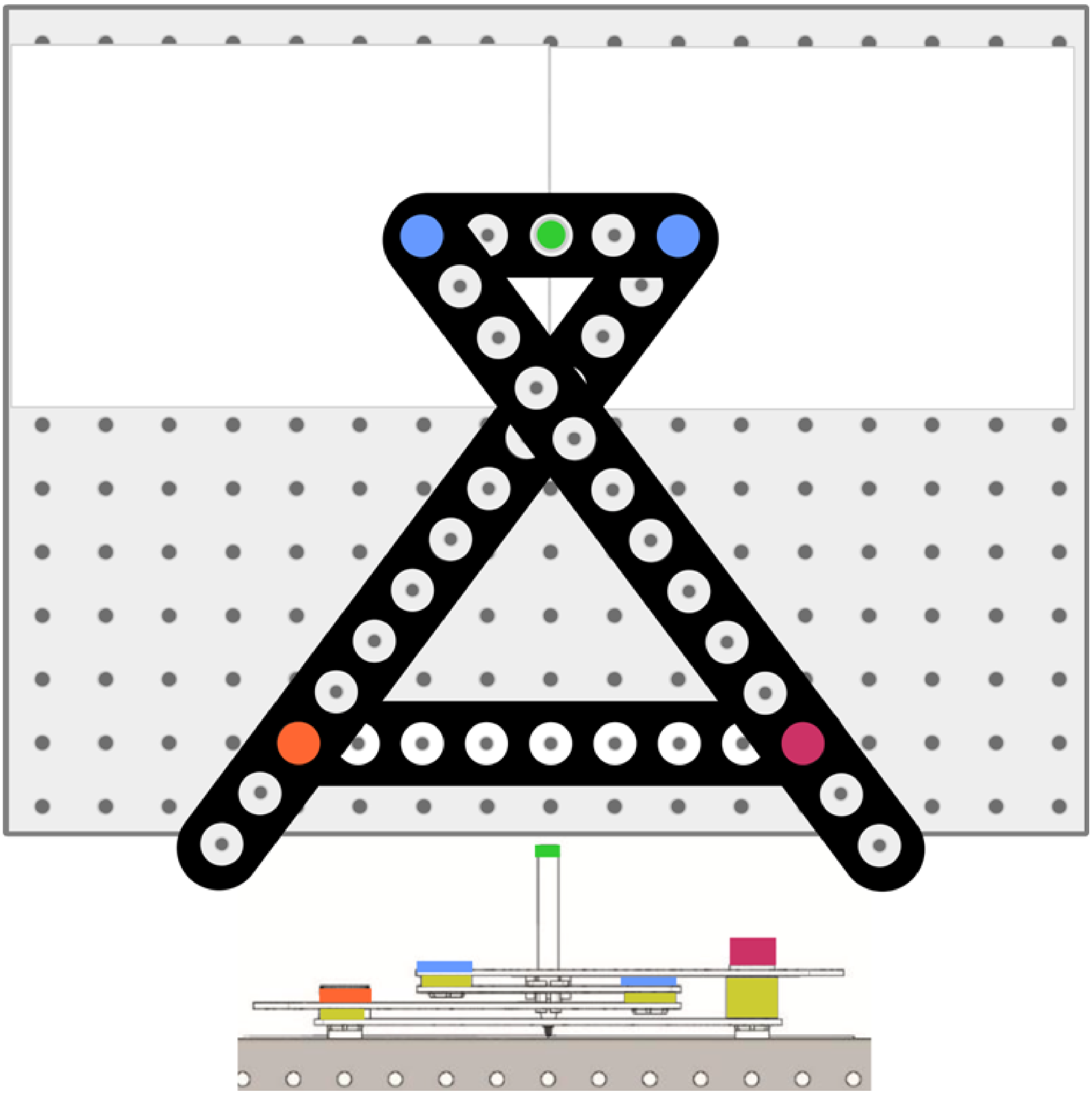




Over to you.....

- Test the system by move the linkages in a circle.
- Observe the resulting motion. Notice that each opposing pair of links remains parallel throughout.
- Make an accurate sketch of it on the template provided in the Student Handout.

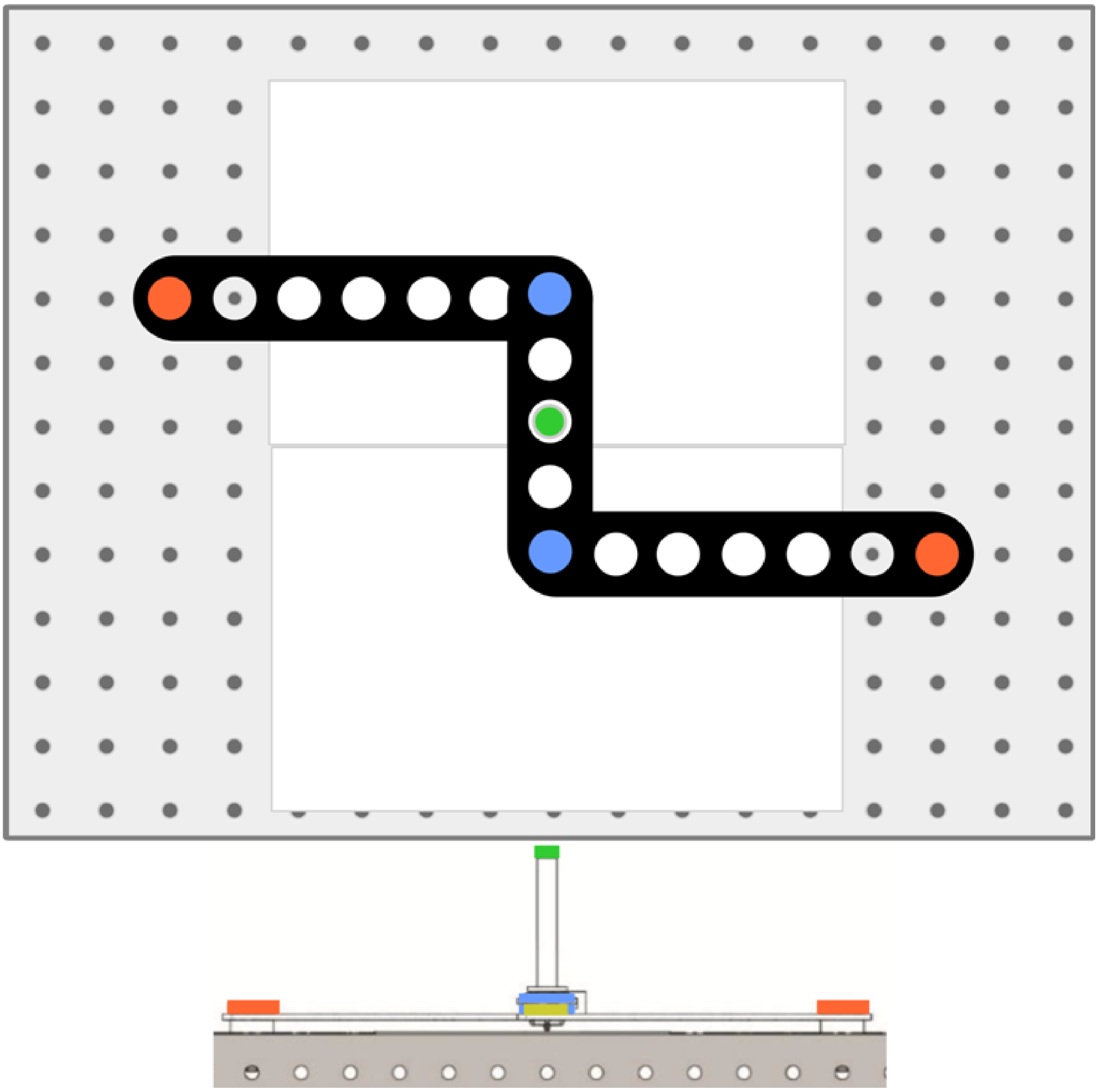
Worksheet 13
The Chebyshev linkage



Over to you.....

- With a marker pen in its centre hole, rotate the five-hole link.
- Observe the resulting motion. Notice the relatively linear movement of the Chebyshev linkage
- Make an accurate sketch of it on the template provided in the Student Handout.

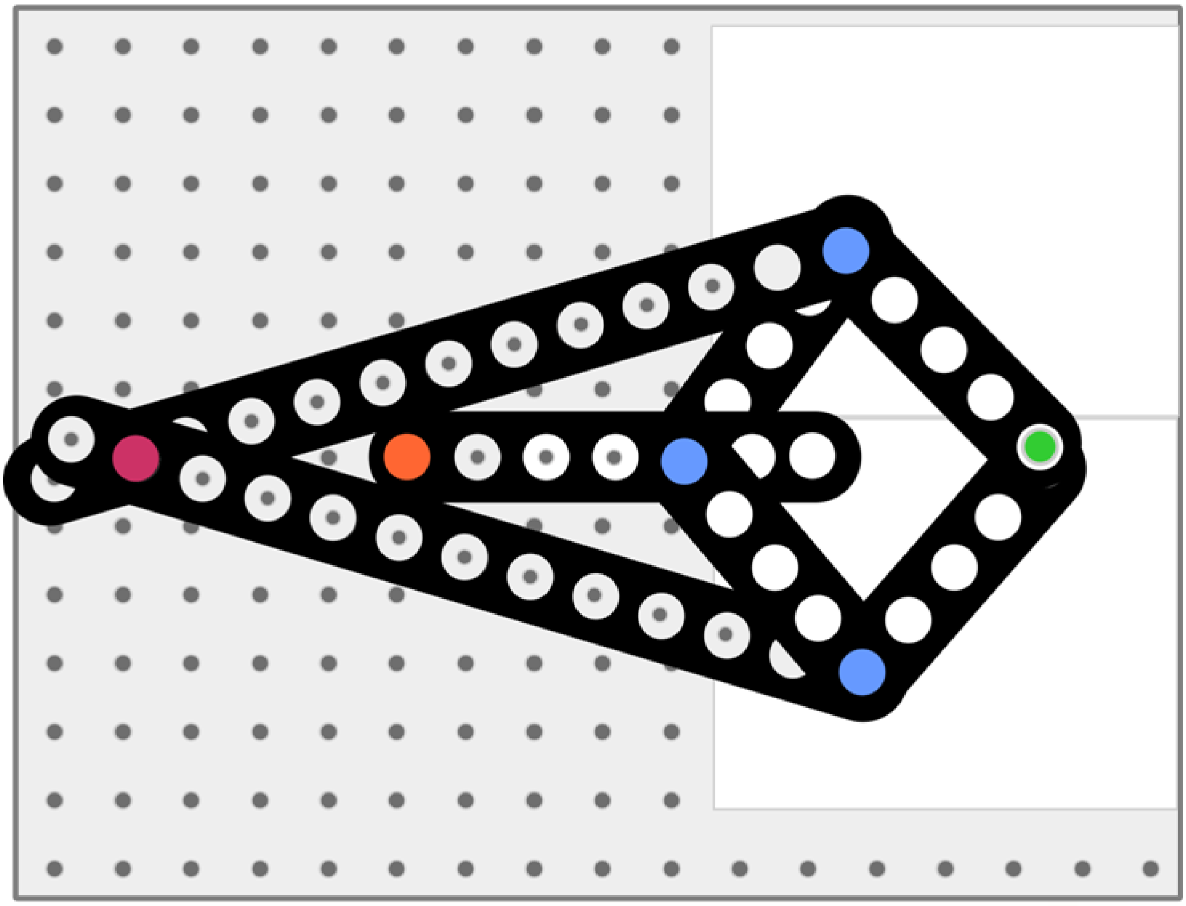
Worksheet 14
The Watt's linkage

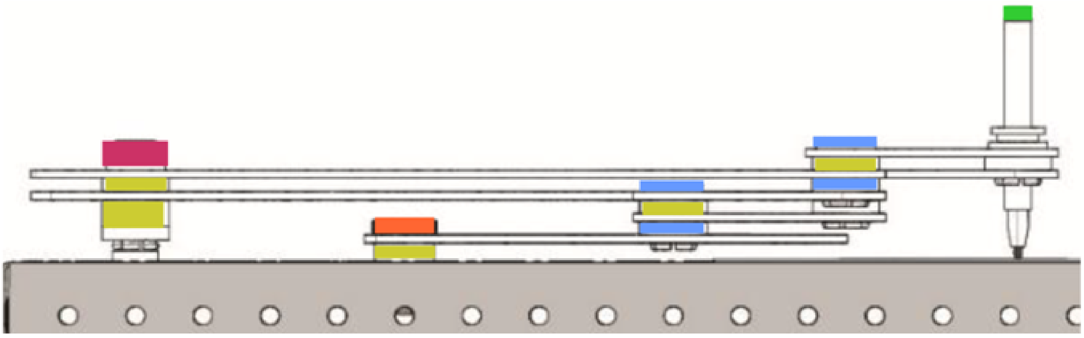


Over to you.....

- Test the mechanism by moving the linkages up and down .
- Observe the nearly straight line motion of the centre bar that results.
- Make an accurate sketch of it on the template provided in the Student Handout.

Worksheet 15
The Peaucellier-Lipkin linkage

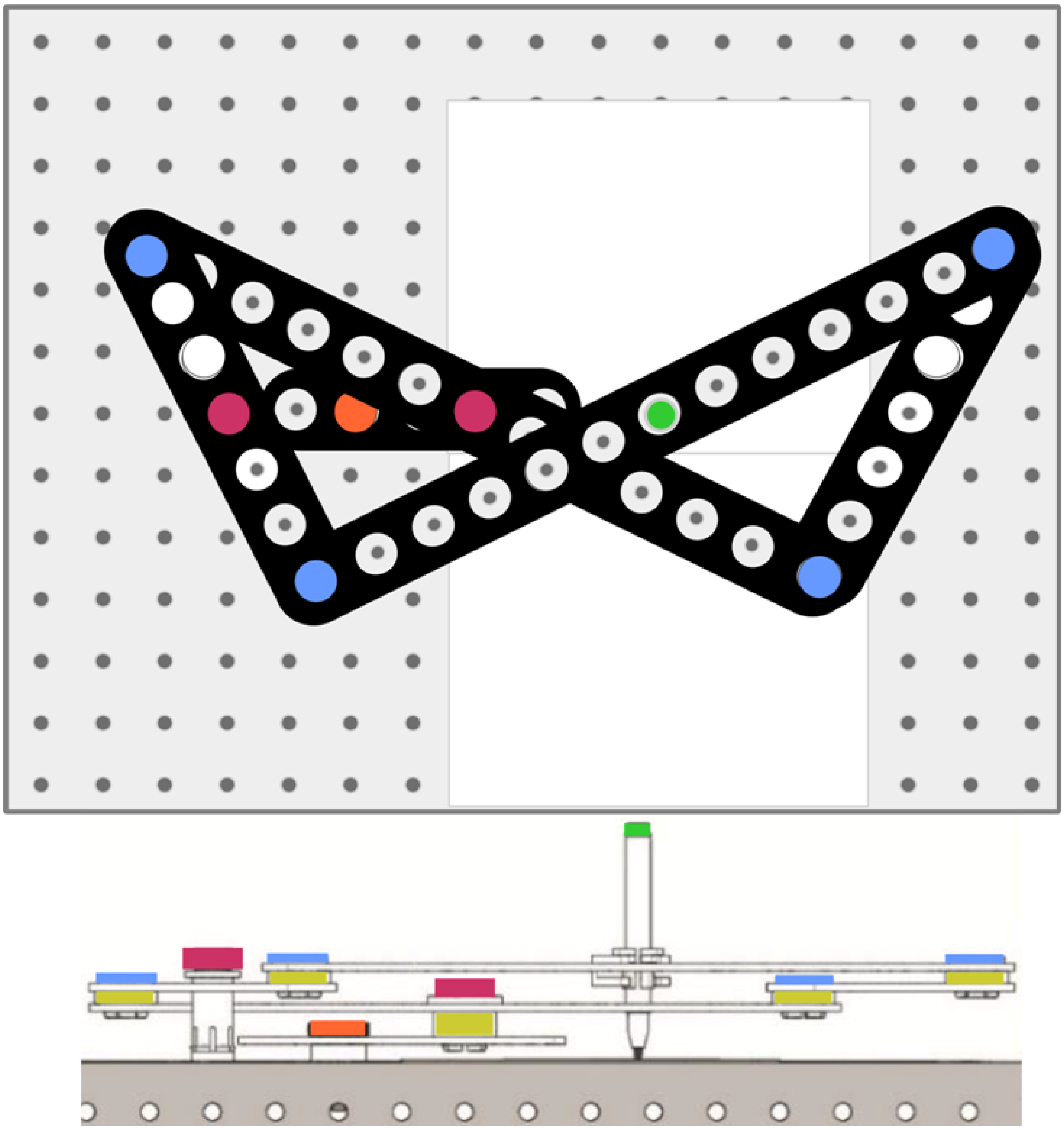




Over to you.....

- With a marker pen in the rightmost joint, move the linkage up and down.
- Observe the true straight-line motion of the Peaucellier-Lipkin linkage.
- Make an accurate sketch of it on the template provided in the Student Handout.

Worksheet 16
The Hart's Inversor

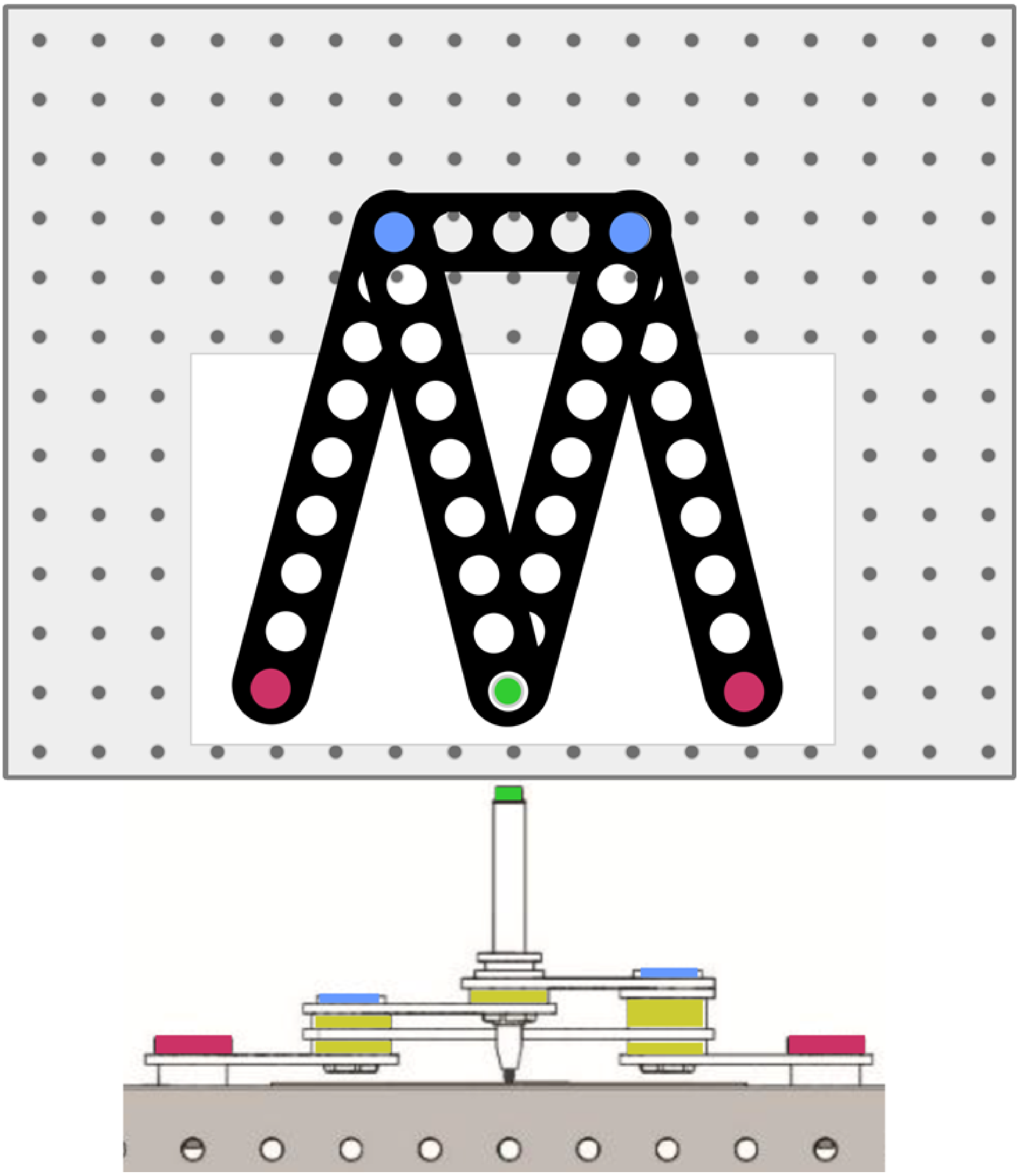


Over to you.....

- With a marker pen in the position shown, move the linkage up and down.
- Notice the straight vertical line on the white board.
- Make an accurate sketch of it on the template provided in the Student Handout.

Worksheet 17

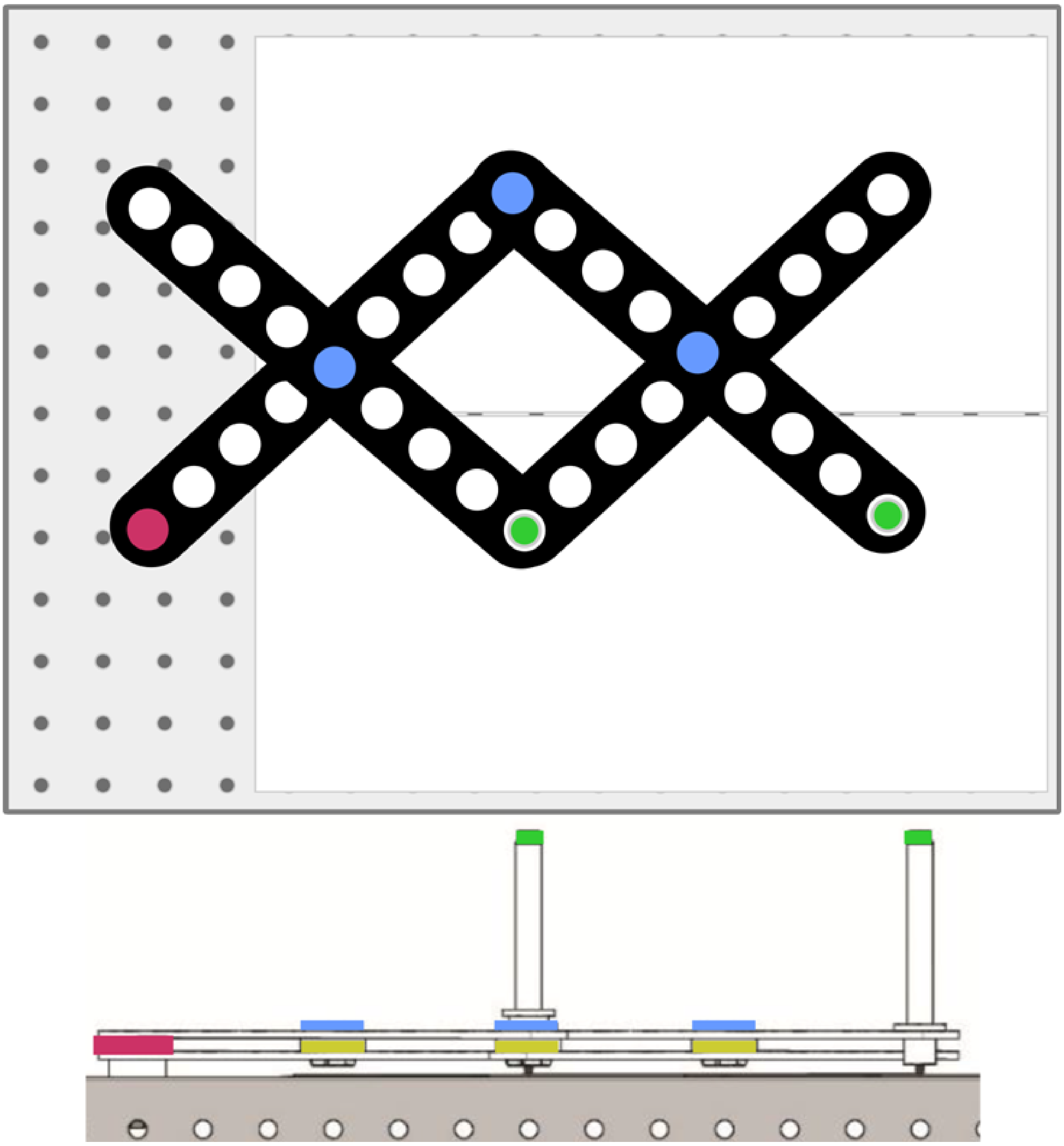
The Robert's linkage



Over to you.....

- Test the mechanism by moving the bottom of the linkage from side to side.
- Notice that this is converted to a near straight line at the lower joint of the Roberts linkage.
- Make an accurate sketch of it on the template provided in the Student Handout.

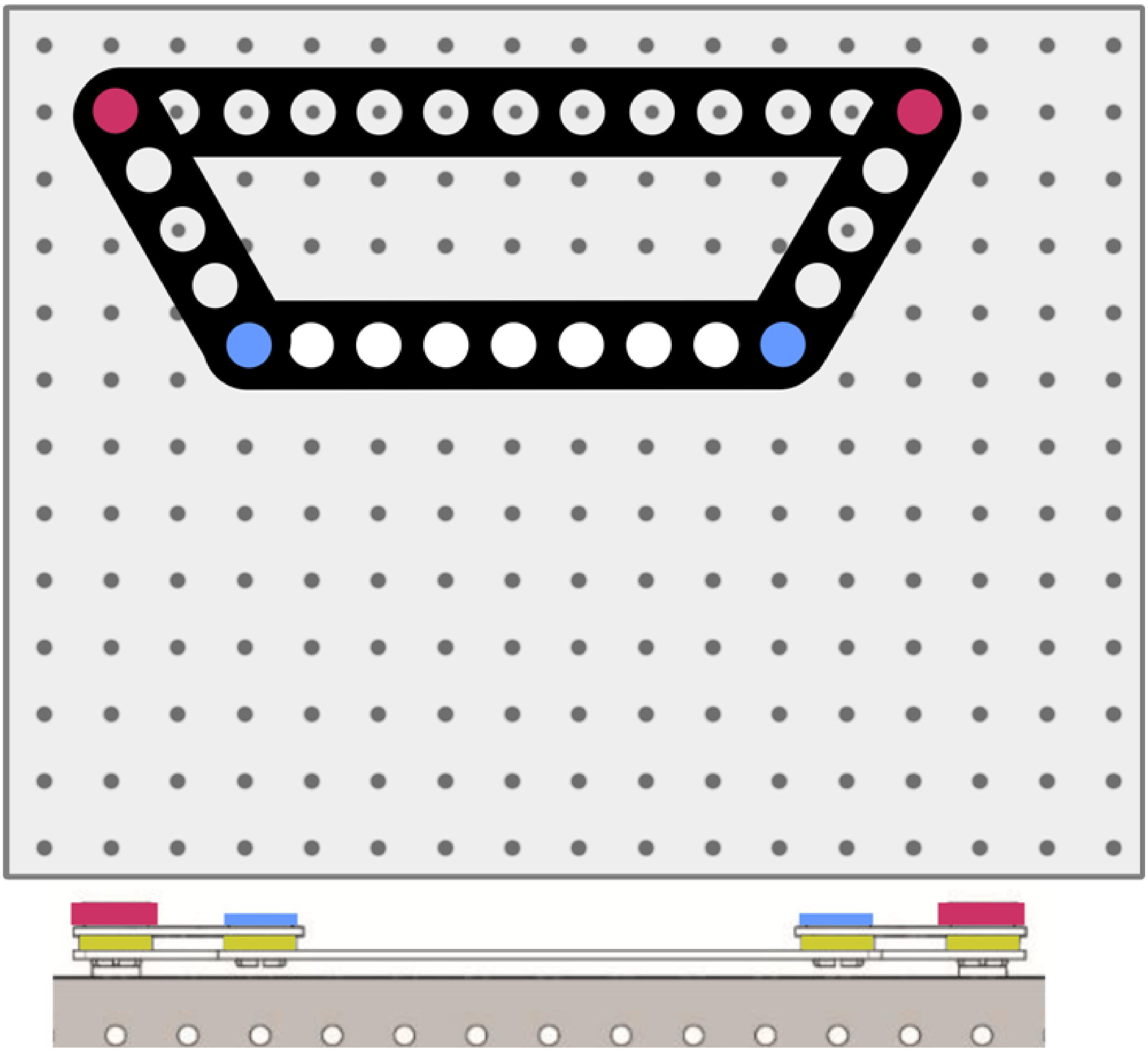
Worksheet 18
The pantograph



Over to you.....

- Observe that moving the pantograph linkage reproduces the motion of one point of the linkage at a second point with increased or decreased size.
- Draw a simple shape on the white board from one of the marker locations to see how the image is scaled either up or down.
- Make an accurate sketch of this on the template provided in the Student Handout.

Worksheet 19
The Ackermann steering linkage



Over to you.....

- Test this mechanism by moving the linkage from side to side and observe the results.
- Move the pivot points to vary the lengths of the linkage arms.
- Observe the effect on the steering geometry.

Worksheet 9-19

Challenge:

Use the results of your investigations and research using resources such as the internet to answer the following questions in the Student Handout:

- Which mechanism provides an alternative to the 3-bar rack and pinion steering mechanism to convert the rotary motion from the steering wheel into the lateral motion needed to control the front wheels in a car?
- Which four-bar linkage is used in the ‘Anglepoise’ reading lamp?
- Which four-bar linkage is used in the horse-head jib in a level-luffing crane, used to move a load parallel to the ground in construction or shipbuilding?
- Which four-bar linkage is in the front suspension of a car to solve the problem of wheels on the inside and outside of a turn needing to trace out circles of different radii without the need for tyres to slip sideways ?
- Which four-bar linkage is used to power an electric train from overhead cables
- Which four-bar linkage is used in locking pliers?

Student Handout

Worksheet 1 - Four-bar linkage

Configuration 1

Right-hand disc angle in degrees	Left-hand disc angle in degrees
0	0
30	
60	
90	
120	
150	
180	
210	
240	
270	
300	
330	

Configuration 2

Right-hand disc angle in degrees	Left-hand disc angle in degrees
0	0
30	
60	
90	
120	
150	
180	
210	
240	
270	
300	
330	

Worksheet 1 - Four-bar linkage

What is the effect of changing the configuration?

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Challenge:

The pedal cycle:

Explain how the four-bar linkage arrangement applies to a cyclist pedalling a bicycle.

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Worksheet 2 - Crank and slider

Linkage assembly attached 30mm from the axis:

Crank angle in degrees	Slider position in mm
0	0
30	
60	
90	
120	
150	
180	
210	
240	
270	
300	
330	

From the graph:

- the maximum linear displacement of the slider ....mm
- the crank angle at which this occurs ....^{0}

Challenges:

1. Slider velocity:

What happens to the velocity of the slider as you rotate the crank at a steady rate?

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Worksheet 2 - Crank and slider

Challenges:

2. Crank linkage position:

Linkage assembly attached 40mm from the axis:

Crank angle in degrees	Slider position in mm
0	0
30	
60	
90	
120	
150	
180	
210	
240	
270	
300	
330	

Effect of this modification:

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Worksheet 3 - Oscillating cylinder

Linkage assembly attached 30mm from the axis:

Crank angle in degrees	Slider position in mm
0	
30	
60	
90	
120	
150	
180	
210	
240	
270	
300	
330	
360	

From the graph:

- the maximum linear displacement of the slider ....mm
- the crank angle at which this occurs ....^{0}

Challenge:

What would be the effect on the motion of using:

- the 40mm hole on the crank disc;

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- a longer slider?

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Worksheet 4 - Scotch yoke

Linkage assembly attached 30mm from the axis:

Crank angle in degrees	Slider position in mm
0	
30	
60	
90	
120	
150	
180	
210	
240	
270	
300	
330	
360	

Use your graph to determine:

- the maximum linear displacement of the slider ....mm
- the crank angle at which this occurs ....^{0}

Challenge:

- Write a short report summarising the mechanical advantages and disadvantages of using this mechanism instead of a crankshaft in a 4-stroke internal combustion engine.

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Worksheet 5 - Slotted link quick return

Crank pin attached 30mm from the centre.
Slotted link attached 140mm from centre of crank.

Crank angle in degrees	Slider position in mm
0	
30	
60	
90	
120	
150	
180	
210	
240	
270	
300	
330	
360	

Use your graph to determine:

- the change in angle needed to move the slider from 0^0 to maximum displacement on its outward stroke;
- the change in angle needed to move the slider back from maximum displacement to 0^0 on its return stroke.

Challenge:

- Investigate the effect of changing the above distances:

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Worksheet 6 - Whitworth quick return

Crank angle in degrees	Slider position in mm
0	
30	
60	
90	
120	
150	
180	
210	
240	
270	
300	
330	
360	

Use your graph to determine:

- the change in angle needed to move the slider from 0^0 to maximum displacement on its outward stroke;
- the change in angle needed to move the slider back from maximum displacement to 0^0 on its return stroke.

Challenge:

- Investigate the effect of changing the above distances: