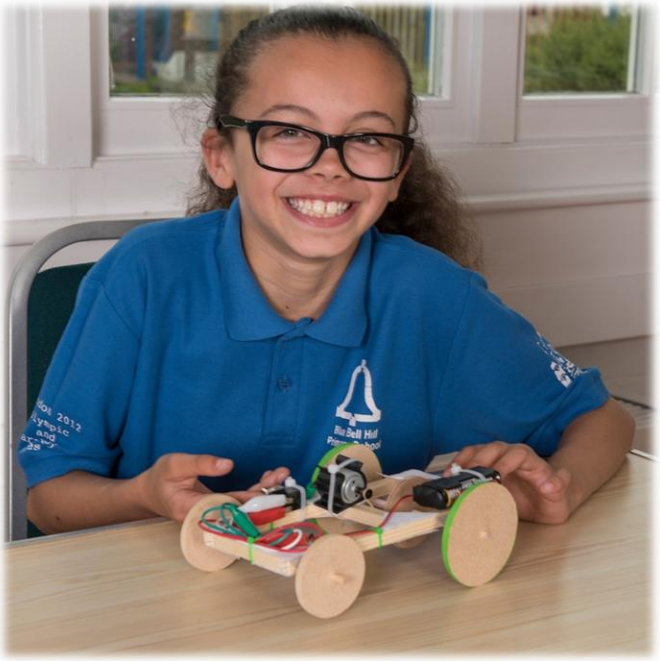
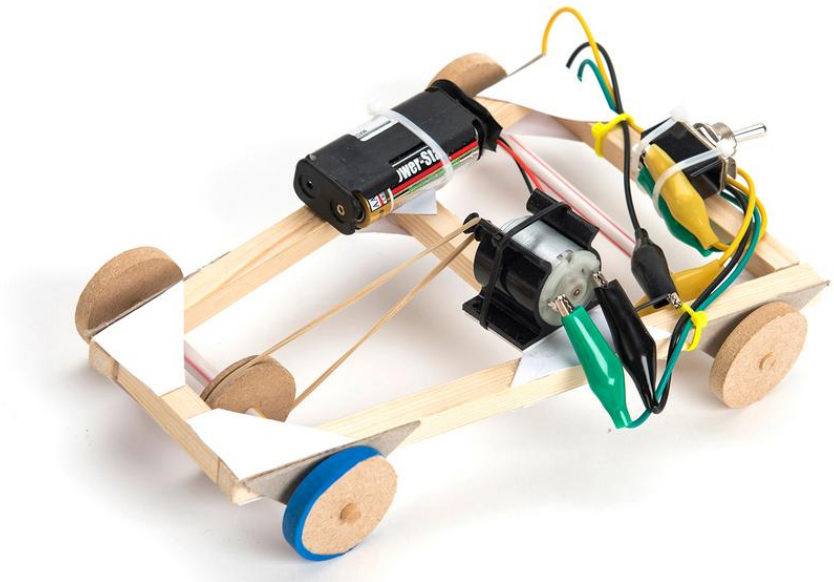
Motorised Vehicles





Lesson Plan

Motorised Vehicles Lesson Plan

- Recommended level – Years 5-6
- Time taken – 6 hours
- Expectation – each pupil to complete one working vehicle
- Additional adult help is recommended

Skills and Learning

STEM Links

- **S**cience: electrical circuits, friction, pulleys
- **T**echnology: structures, mechanical systems, electrical systems, designing and making
- **E**ngineering: design, build, test and improve products
- **M**athematics: measurement, speed, converting units
- draw 2-D shapes, measure angles, measure distance and time, calculate average speed

Curriculum Learning Objectives – it is recommended to cover these topics prior to the exercise so that the pupils are reinforcing their knowledge and understanding, rather than meeting the topics for the first time.

Science: Electricity

Pupils should be taught to:

- construct a simple series electrical circuit, identifying and naming its basic parts
- recognise that a switch opens and closes a circuit
- recognise some common conductors and insulators, and associate metals with being good conductors
- use their circuits to create simple devices
- represent a simple circuit in a diagram using recognised symbols
- pupils should be taught about precautions for working safely with electricity

Science: Forces

Pupils should be taught to:

- identify the effects of friction that act between moving surfaces
- recognize that some mechanisms including pulleys allow a smaller force to have a greater effect

Design and Technology

Through a variety of creative and practical activities, pupils should be taught the knowledge, understanding and skills needed to engage in an iterative process of designing and making.

When designing and making, pupils should be taught to:

- apply their understanding of how to strengthen, stiffen and reinforce more complex structures
- understand and use mechanical systems in their products (for example pulleys, wheels and axles)
- understand and use electrical systems in their products (e.g. series circuits incorporating switches and motors)

Mathematics: Measurement (Year 3)

Pupils should be taught to:

- measure lengths

- compare duration of events
- measure angles in degrees
- calculate average speed

Vocabulary List

- Pulley – a grooved wheel over which a drive belt can run.
- Drive belt – the belt which connects and transfers movement between two pulleys
- Pulley ratio – the ratio of the large to the small pulley diameters
- Axle – a central shaft for rotating wheels.
- Bearing – a part that retains an axle in position whilst allowing it to rotate.
- Series circuit – a circuit with only one possible path for the current.
- Short circuit – an incorrect route in a circuit which misses out certain components and can cause the circuit to fail.

Associated Resources

- Motorised Vehicles Presentation – this is to be followed when running the activity in class.
- Motorised Vehicles Design Sheet – this is to be printed out, one for each pupil.
- Motorised Vehicles Worksheet – this is to be printed out, one for each pupil. Some suggested answers are given at the end of this Lesson Plan.
- Motorised Vehicle Instructions – this is for the teacher to follow to make a sample vehicle.
- Pulley Animation – this is to be shown during slide 9 of the presentation, to demonstrate how pulleys work.

Equipment needed

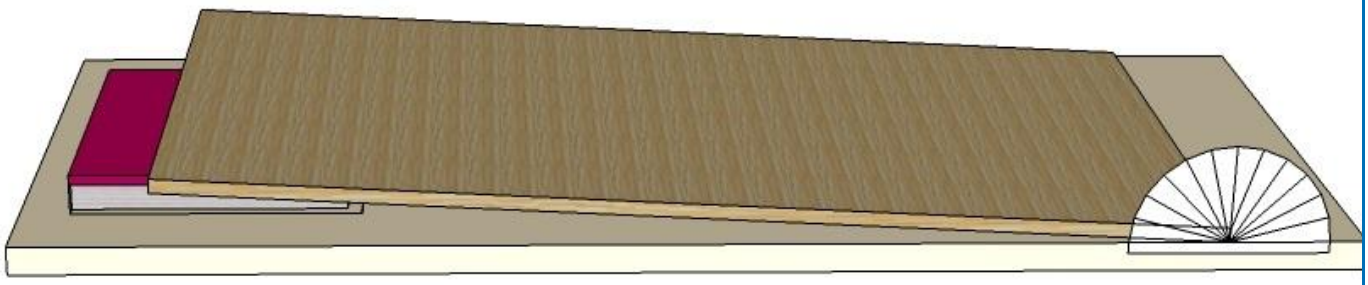
- Zinc chloride AA batteries (80)
- Square section wood 8mm x 8mm (50 lengths of 59cm)
- Wooden wheels 54mm diameter (100)
- Wooden wheels mixed sizes (100)
- Motors (30)
- Rubber bands (454g box)
- Toggle switches (30)
- Motor mounting clips (30)
- Battery holders 2xAA (30)
- Snap battery connectors (50)
- Crocodile leads (90)
- Card axle supports (500)
- Card triangles (500)
- Plastic pulleys mixed sizes (60)
- Wooden pulleys 74mm (1 pack of 10)
- Small plastic motor pulleys (30)
- Small plastic gears for motor (20)
- Dowel 5mm diameter (20 lengths of 60cm)
- Jumbo paper straws (200)
- Cable ties (300)
- Sandpaper (25 sheets)

Check you have received the correct contents in your class kit. Try pushing both the wooden wheels and the wooden pulleys onto the dowel to check they fit tightly. (There can be a slight variation in the diameter of the dowel due to the wood's moisture content. If the wheels are difficult to fit you can sandpaper down the end of the dowel slightly, and if they are slightly loose on the dowel you can glue them on.) Check the plastic motor pulleys

are a tight fit on the motor shafts. Check the dowel slides easily inside the straws. Please let TTS know if there are any problems as soon as possible.

Tools and consumables needed (not included in class kit):

- A small plastic bowl for each pupil would be useful, for them to collect their electrical parts. Otherwise, the motors tend to roll off the table and get lost!
- Ruler
- Pencil
- Paper
- Calculator
- Pointed scissors
- Low melt glue gun and glue sticks. **Note: High melt temperature glue guns should not be used by pupils, as they can cause nasty burns.**
- Junior hacksaw, vice or bench hook
- Balloons and/or old bicycle inner tube from mountain bike or similar
- Tape measure
- Stop watch
- Protractor
- Ramp (or sheet of plywood or similar propped up on books).



- Chalk or masking tape to mark out the race track
- Shallow slope for the race track (e.g. two sheets of plywood or similar propped up on some books – see picture in Preparation Needed)
- Duct tape to join the ramp parts together

Preparation needed

The mixed plastic pulleys can be a very tight fit on the 5mm diameter wooden dowel. It is useful to pre-drill or ream the pulleys to enable them to be fitted more easily. They need to fit tightly on the rod after drilling, but it must be possible for the pupils to fit them on the rod by hand.

You may want to cut the wooden rods in half and give a 30cm length to each pupil. They can then use this length to make both their axles. It is convenient to cut the rod using secateurs, to avoid splitting it. Do not let pupils use the secateurs themselves for safety reasons.

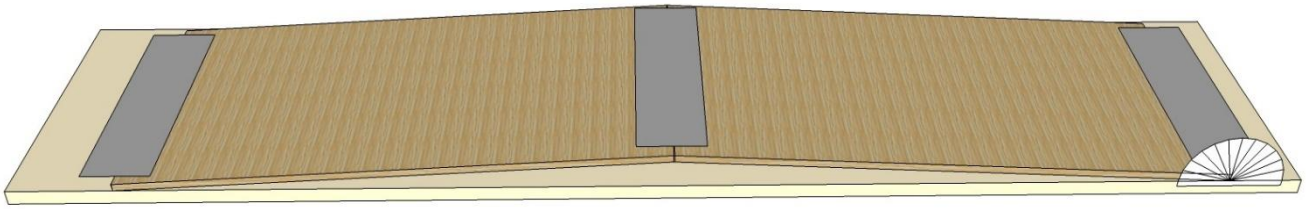
You may want to give each student 1.5 lengths of square wooden rod to use for their frame. They then need to plan their frame so that it can be made with the wood provided.

Build a sample vehicle to explore any pitfalls, and to demonstrate to the pupils what they will be making and how it works. Instructions for building a sample vehicle are given in the instruction sheet ‘How to make a motorised vehicle’.

Print out a copy of the worksheet and the design sheet for each pupil.

Additional adult help is useful; you could invite in some adult helpers for example.

The vehicles can be tested on the school floor (e.g. in the hall) or in the playground. You need to lay out a straight race track (with start and finish line) for the vehicles which includes a shallow slope of about 10°, so that the effect of different pulley ratios can be investigated. To construct the slope, you can use a sheet of plywood board propped up on some books to go up, then another one to go down again. If you put duct tape across the join it makes it easier for the vehicles to cross from one to the other.



Slope made from two pieces of wood, propped up in the middle and joined with duct tape.

The start could be on the slope; otherwise, you may need more duct tape between the slope and the floor so the vehicles can get onto the slope. Try out your vehicle on the track to make sure it works – you will probably need rubber tyres (e.g. slices of balloon or bicycle inner tube) to get the wheels to grip, particularly when going up the slope.

Once the initial build is complete pupils can test their vehicles on the track. They will need to measure the distance (in meters) and find out how long it takes to complete this (in seconds). They then divide the distance by the time to calculate the average speed in m/s. They can then make changes to their car in order to help it go faster. At the end a competition is held in which each car races along the track, and the times are recorded on a leader board. The winning car should be examined closely by the pupils, to try and identify what design features were responsible for its success.

Risk Assessment

Conduct a risk assessment before undertaking the activity. A sample risk assessment is given below; you can use this as a starting point when writing your own. (L=low, M=medium, H=high)

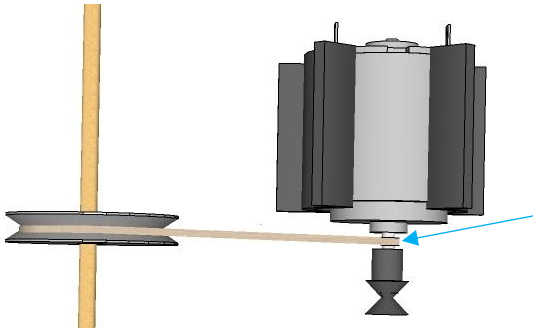
Activity	Identified Hazard	Initial Risk Rating L/M/H	Control Measures	Controlled Risk Rating L/M/H
Use of glue guns	Burns	H	• Children should be supervised by a responsible adult at all times when using the glue guns. • Explain to children how to use the glue guns. • Warn them that the ends are very hot. Use only low melt temperature glue guns. If burned hold under running water for ten minutes. • Don't switch on the glue guns until after the safety briefing. • In some schools, children wear safety goggles when using glue guns.	M

Accidentally short-circuiting battery	Burns, smoke inhalation	M	• Explain how to avoid short circuits. • Use only zinc chloride cells, not alkaline or re-chargeable ones as these can get very hot if short circuited.	L
Use of scissors	Injury e.g. to fingers	M	• Make the children aware of the dangers. • Do not give out the scissors until after the safety briefing.	L
Use of secateurs	Severe injury, e.g. to fingers	H	• **Do not** allow the pupils to use these. Only for use by responsible adults.	L
Use of junior hacksaws	Injury, e.g. to fingers	M	• Make the pupils aware of the dangers. • Explain how to use the hacksaws safely. • Only use the hacksaws in combination with a vice or bench hook. • Do not give out the hacksaws until after the safety briefing.	L
Use of cable ties	Cable tying fingers and cutting off blood supply	M	• Explain the dangers to the pupils. Cut cable ties off fingers immediately.	L
Running extension leads along floor for glue guns	Trip hazard	M	• Avoid using extension leads if possible. • Otherwise make sure extension leads are run where they cannot be tripped over.	L
Damaged extension leads or glue gun leads	Electrocution hazard	H	• Conduct a visual check of all electrical items before session, to ensure the leads are undamaged.	L

Teacher notes – referring to the relevant slides in the Motorised Vehicles Presentation

Slide 1	**Design a motorised vehicle** • Point out the variety of designs shown on the slide, including different wheel sizes at the front and back and different frame designs.
Slide 2	**Examples of vehicles** • An ambulance is used for emergency medical care, transporting patients to hospitals and providing life-saving treatment during transit. • The lunar rover was used during Apollo missions for astronaut transportation, carrying equipment, collecting samples and exploring the Moon's surface. • A racing car is used for high-speed competition, precision driving, performance testing and motorsports events on specialized racing circuits. • A Land Rover is used for off-road driving, transportation, military operations, farming, towing and exploring rugged terrain.

Slide 3	**Examples of pulleys** • The pulley in a roller blind is used to wind the blind up and down by pulling the string. • The spinning wheel has a large pulley operated by a foot pedal. This is connected to a smaller pulley on the bobbin which turns at a much higher speed to twist the thread. • The fan belt in a car engine transfers power from the engine to drive components like the alternator and water pump.
Slide 4	**Context** • This slide is intended to relate the activity to a possible real-life scenario. • Formula 24 is a competition for secondary school pupils to design, build and race an electric kit car. • More details can be found here: https://www.greenpower.co.uk/
Slide 6	**Safety** • First ask the pupils to identify possible hazards and possible ways to reduce the risk. • Don't burn yourself with the glue gun. You could ask an adult to supervise the gluing station. • To avoid cutting yourself with the saw, use a vice or bench hook to hold the piece of wood you are cutting. • Be careful not to cut yourself with the scissors. • Don't cable-tie your fingers.
Slide 7	**Parts of the vehicle** • Switch on your sample vehicle to show the pulley system operating to drive the wheels. • Point out the different parts of the vehicle.
Slide 8	**Using wheels, axles and bearings** • Hold your sample vehicle up and spin the non-driven wheels, to show how the axle rotates freely in the bearings.
Slide 9	**Using a pulley system** • Show the pupils the pulley animation (see associated literature). Running the animation shows how, using the pulley system, many turns of the motor give rise to fewer turns of the driven pulley (and hence the wheels). • This gives higher torque ('turning force') and lower rotational speed. • If the students leave a gap between the motor and the motor pulley as shown, the rubber band can also be placed directly on the motor shaft, giving an even higher pulley ratio.



Gap between motor and motor pulley.

- There is also a gear which can be used in place of the motor pulley. This will give a lower pulley ratio. It is recommended to start by using the motor pulley.
- The pupils could experiment with these at the end to try altering the performance of their vehicle.

Slide 10

How the vehicle works

- Try out the sample vehicle, both on the flat and up a gentle slope.
- Discuss how the vehicle works, and how the pulley and wheel sizes will affect the performance.
- In general, a small pulley diameter on the motor end and a large pulley diameter on the driven axle gives high torque and good hill climbing ability.
- A slightly larger diameter pulley on the motor end and/or smaller diameter pulley on the driven axle should give higher speed. However, it can also take longer for the vehicle to get up to speed, due to the reduced torque.
- If the pulley ratio is too low, the vehicle may not climb the slope at all, and may not even go on the flat due to significantly reduced torque.
- In general, it is preferable to have the driven pulley and the driven wheels similar in size, or the driven pulley slightly smaller. If the driven wheels are much bigger than the driven pulley, the vehicle may not go.

Slide 11

Electrical parts

- You can hold up each part in turn and ask the pupils to name it.
- They are: motor, switch, battery and wires or crocodile leads.
- Point out the circuit symbol (shown below each component) which relates to each of the components.
- Explain that these are used to represent the components on a circuit diagram; they are much easier to draw than the actual components!

Slide 12

How the electric circuit works

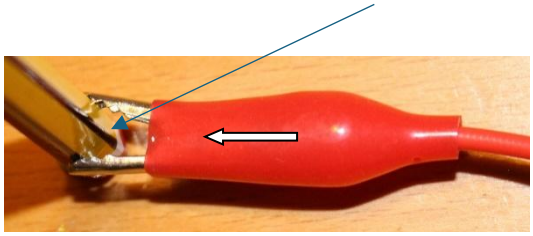
- Explain that the diagram on the right is the circuit diagram. It is a representation of a circuit, and can be used when designing or trouble-shooting an electric circuit.

Slide 13

Avoid short circuits

- It is very common for pupils to accidentally short circuit their batteries whilst wiring up their circuits.
- Zinc chloride cells are provided in the class kit – these don't get too hot when short-circuited.

- If you need to replace your cells, be careful to buy zinc ones (e.g. the cheap ones from discount stores which say 'zinc' on them. Alkaline or rechargeable batteries should not be used as they can get very hot if short-circuited.
- Pupils often slide the plastic sleeves back when connecting their crocodile clips. You could ask them not to.
- If the sleeves have been pushed back, you can clip the crocodile clip onto a pencil as shown below, in order to slide the sleeve back on.



Slide 14

Connecting the crocodile clips

- Pupils often clip the crocodile leads onto the plastic insulation on the wires from the battery, instead of onto the metal ends.
- Pupils sometimes clip the crocodile leads onto the motor shaft instead of the motor contacts.
- Pupils sometimes clip the crocodile leads onto the switch toggle instead of the switch contacts.

Slide 15

Make your circuit

- You could ask pupils to come up and collect their parts in a small bowl, to save you having to hand them out.
- It is recommended for pupils to have three different coloured crocodile leads, as they are less likely to get them mixed up and create a short circuit.
- The snap battery connector can be quite hard to push on.
- It is a good idea to demonstrate how to connect up the circuit, including showing the pupils which way round to fit the cells.
- The flat end of the cell should be pushed up against the spring in the battery holder.
- Pupils could lay their components out in a triangle, then connect one wire from the switch to the motor, one from the motor to the battery and one from the battery to the switch.

Slide 16

Materials available for your vehicle

- It would be useful to show the pupils the actual materials they have to make their vehicles.
- It is important to choose a thin rubber band for the drive belt (e.g. 1.5mm x 1.5mm). Otherwise, it can create too much friction and prevent the motor from turning.
- The length of rubber band recommended is about 2-3 times the diameter of the pulley selected.
- The length of rubber band can be measured with a ruler, with the rubber band laid out straight.

Slide 17

Design your vehicle

- The recommended width of the frame is around 11cm, due to limitations on the length of the axle.
- The recommended frame length is about 18cm to 28cm long. For a large pulley, a longer frame is recommended.
- Don't use smaller driven wheels than the size of driven pulley.
- The non-driven wheels can be any size.
- Check that the pupils' designs look feasible before they embark on making their vehicle.

It is a good idea to ask the pupils some leading questions before they embark on their designs, to help them avoid a number of common pitfalls. Show them the sample vehicle so that you can point out the issues. Suggested questions include:

1. Why do you need to fit the rubber band onto the pulley before you attach your driven axle? (This is because you can't fit it after you have attached your axle!)

2. What will happen if your driven pulley is touching the frame? (It will rub when it rotates, or may not be able to rotate at all.) How can you avoid this? (Mount your axles holders far enough away so that the pulley doesn't touch the frame.)

3. If your wheels are jammed up hard against the ends of the straws, what will happen? (They will rub and slow the vehicle down; that is why you need to leave a gap.)

4. If your straws are jammed up hard against the pulley what will happen? (They will rub and prevent the axle turning as fast.)

5. What will happen if your pulley is a larger diameter than your wheels? (The pulley will be in contact with the ground.)

6. If your wheels slip on the ground, how could you increase the friction? (Add tyres made from slices of balloon or bicycle inner tube.)

7. If the driven wheels still slip on the ground, you can move the centre of gravity. Whereabouts do you want the centre of gravity of your vehicle to help the driven wheels grip the ground? (Keep your centre of gravity near the driven end, for example by mounting your battery that end.)

8. If your driven axle is able to slide sideways, for example your straws are not glued to the axle holders, or there is a big gap between the straw and pulley, what is likely to happen? (The rubber band is likely to come off the pulley when in use. That is why the gap needs to be very small.)

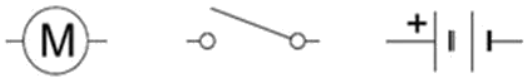
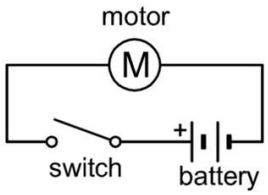
9. Why might your motor stall? (When your motor stalls it can't rotate. This is usually because you have put too high a load on it, for example by using a driven pulley which is too small, wheels which are too large, a drive belt (rubber band) which is too tight, or by trying to climb too steep a slope.)

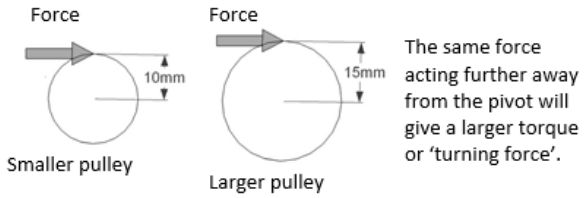
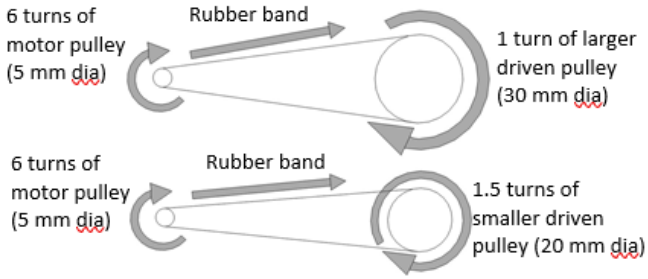
10. Why should you keep your wires away from the rotating parts? (The wires could get caught and stop the parts moving.)

Slide 18	**Make your outer frame** • Check the length carefully before cutting the wood!
Slide 19	**Fit your non-driven axle** • You can smooth the very ends of the axle so the wheels go on easily. • The wheels should fit tightly on the axles. • If the wheels are loose, you can glue them on. • If the wheels are too tight to fit, you can sand the axle down slightly until they just fit. • If the scissors are too rounded to fit in the holes in the axle holders, the holes can be enlarged carefully with a pencil instead.
Slide 20	**Fit your driven axle** • If the pulley is loose then you can glue it on. • The plastic pulleys may be very tight – it is useful to drill or ream them out a little to help them go on. • If it is very tight, you could clamp the axle vertically in a vice and push the pulley down along the axle. • Pupils may need help fitting their pulleys.
Slide 21	**Fit your bearings** • Round out the cut ends of the straw with a pencil.
Slide 22	**Fit your motor** • If you push the motor into the motor mount from above, you can snap the motor mount. It is recommended to push the motor into the mount from the end.
Slide 24	**Fit your motor (cont.)** • If the pulleys are not in line, the rubber band may fall off the pulley during operation. • If you put a slip knot in the rubber band to hold it onto the pulley during fitting then you need to untie the knot. • Don't fit the rubber band on the motor pulley until after you have cable-tied the motor firmly in place.
Slide 25	**Complete your vehicle** • Be very careful not to cut the wires when trimming the ends off the cable ties. • To maximise grip, the centre of gravity should be over the driven wheels. • The battery can be placed near the driven wheels to help achieve this. **In case some of your pupils have finished while others are still completing their vehicles, here are some suggestions for extension activities:**

- Tie two vehicles back-to-back with string and have a tug of war.
- Compare which vehicles go faster on the flat and which go better up a slope, and see if there is a relationship with pulley ratio.
- Try changing between using the rubber band fitted to the motor pulley, the rubber band running on the motor shaft and the rubber band running on the groove in the white gear, to find out the effect on performance.
- Find out the effects of different sizes of wheels.
- Decorate the vehicle frame, wheels etc. with felt tip pens.
- Try using two electric circuits to make a four-wheel drive vehicle and see if this goes any faster, particularly up the slope.
- Convert the speed in m/s into mph and compare with how fast a car goes on the road.

Motorised Vehicles Worksheet - suggested answers

<table>
<tr><td colspan="2">Name these electrical parts:
    
Motor Switch Battery Crocodile lead (or wire)</td></tr>
<tr><td>Draw your circuit using these circuit symbols, using lines to represent the wires. Label the components.
  </td><td>  </td></tr>
<tr><td>Is metal an insulator or a conductor?</td><td>A conductor</td></tr>
<tr><td>Is plastic an insulator or a conductor?</td><td>An insulator</td></tr>
<tr><td>What could happen if you short circuit your battery?</td><td>I could heat up or melt your battery holder and possibly burn my fingers.</td></tr>
<tr><td>What will happen if you leave the circuit switched on for a long time?</td><td>I will drain the battery.</td></tr>
<tr><td>If you measure a time T to travel a distance D, how do you calculate the average speed?</td><td>Average speed = distance D / time T</td></tr>
<tr><td>What was the average speed of your vehicle?</td><td></td></tr>
<tr><td>Which of your items are acting as bearings?</td><td>The straws act as bearings.</td></tr>
<tr><td>Why does the pulley need to be a tight fit on the axle?</td><td>It needs to be a tight fit so that when the pulley is driven, the axle turns. Otherwise, it will slip.</td></tr>
<tr><td>Why do the wheels need to be a tight fit on the axles?</td><td>The wheels need to be a tight fit so that when the axle turns the wheels also turn.</td></tr>
</table>

If your vehicle goes backwards, what can you change to make it go forwards?	I can swap over the crocodiles attached to the two motor terminals.
Which goes faster, a vehicle with a larger driven pulley or one with a smaller driven pulley?	A vehicle with a smaller driven pulley goes faster (unless it is trying to go so fast that the wheels slip on the ground or the motor stalls and won't go round.)
Which goes up steeper slopes, a vehicle with a larger driven pulley or one with a smaller driven pulley?	A vehicle with a larger driven pulley goes up steeper slopes (as long as the wheels grip the slope).
Extension Questions	
Why do cars have rubber tyres?	It helps them grip the road better, by increasing the friction between the wheels and the road. This is particularly important when braking, going round corners, accelerating and going uphill.
If you were cycling up a steep hill, would you choose a gear which gives you low speed and high torque ('turning force') or high speed and low torque?	I would choose a gear which gives low speed and high torque.
Explain why the size of the driven pulley affects the hill climbing ability of your vehicle. 	When using a larger driven pulley, the speed is lower but the torque ('turning force') is higher, which enables you to get up the hill.
Explain why the size of the driven pulley affects the speed of your vehicle. 	For the rubber band to move the same distance as one turn of the larger driven pulley, the smaller driven pulley has to turn 1.5 times. Therefore, the axle turns faster.