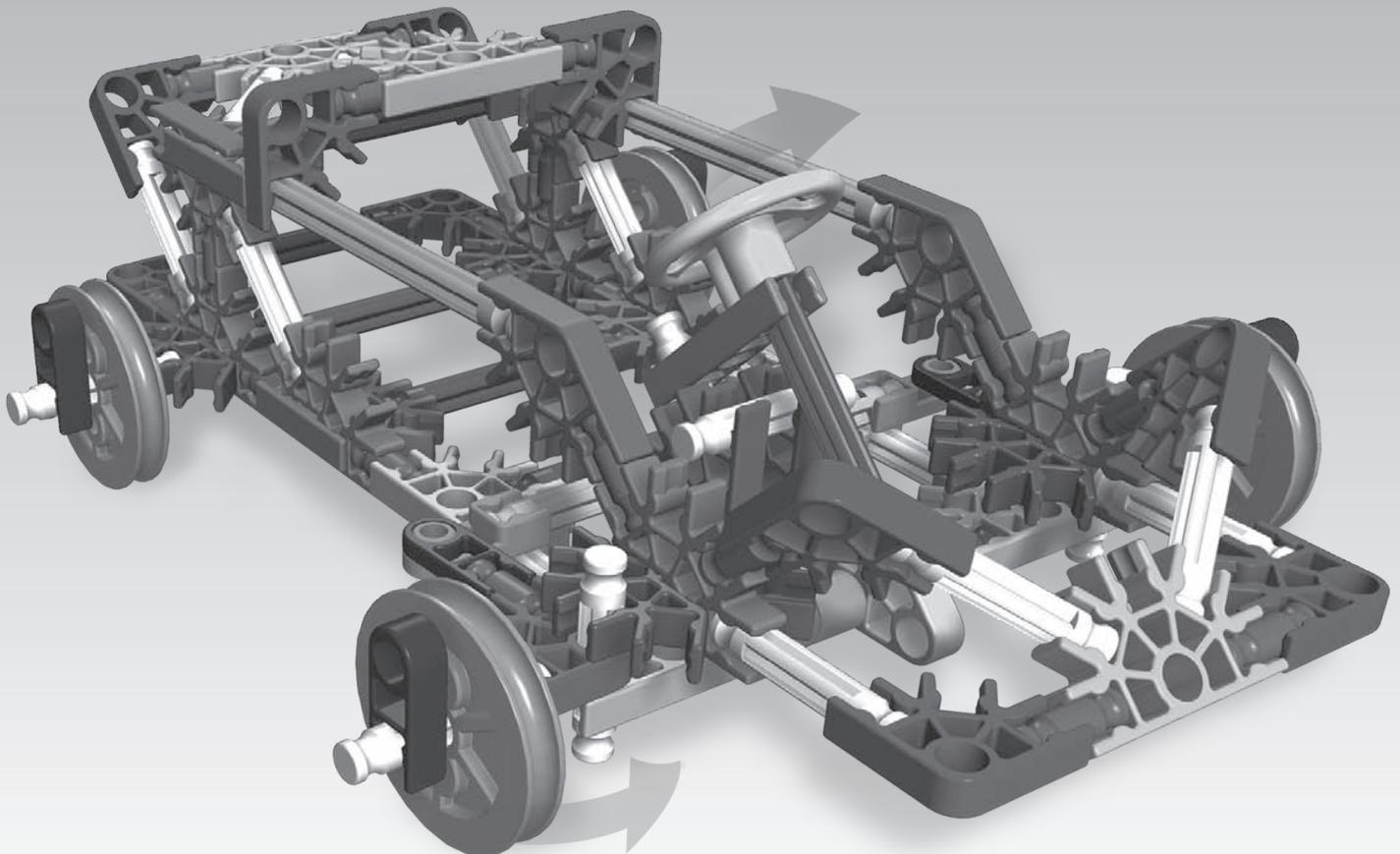
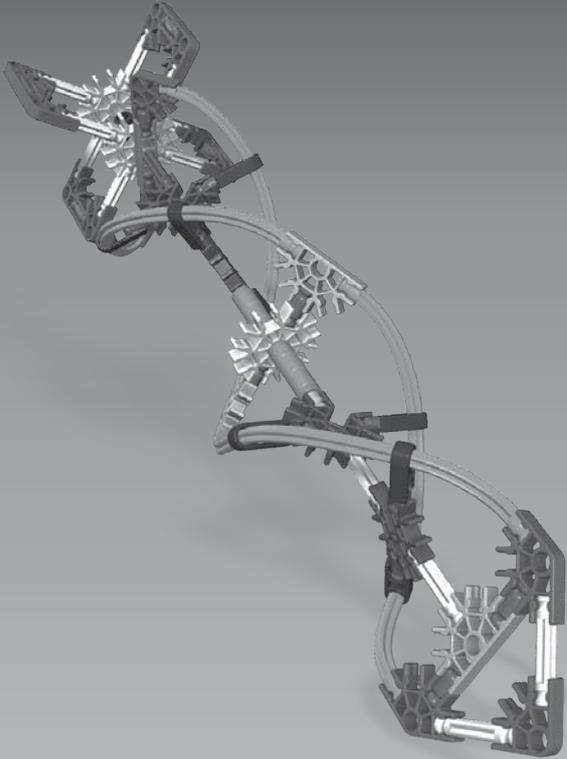


TEACHER'S GUIDE

WHEEL & AXLES AND INCLINED PLANES UNDERSTANDING MECHANISMS



Understanding Mechanisms:

Wheels and Axles and Inclined Planes Teacher's Guide

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 **WARNING:**
CHOKING HAZARD - Small parts.
Not for children under 3 years.

A Note About Safety

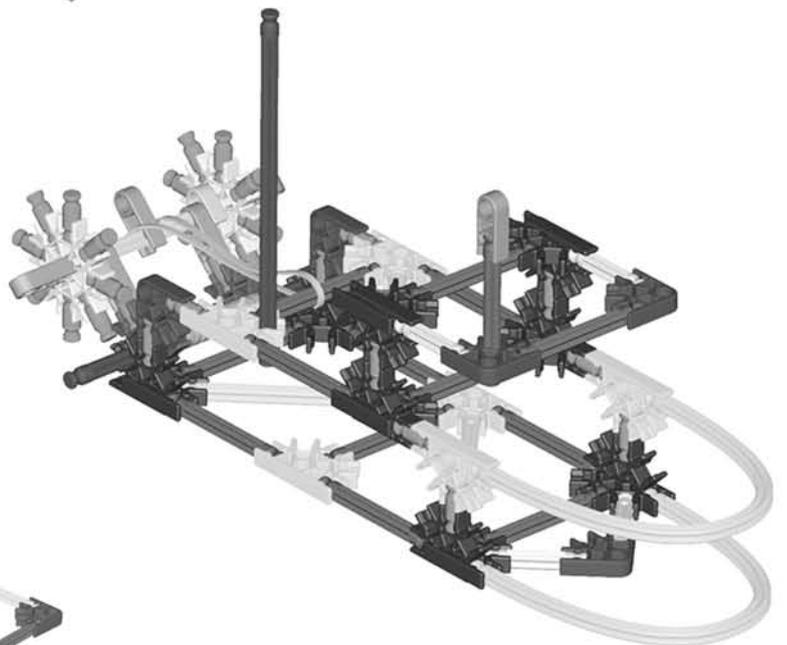
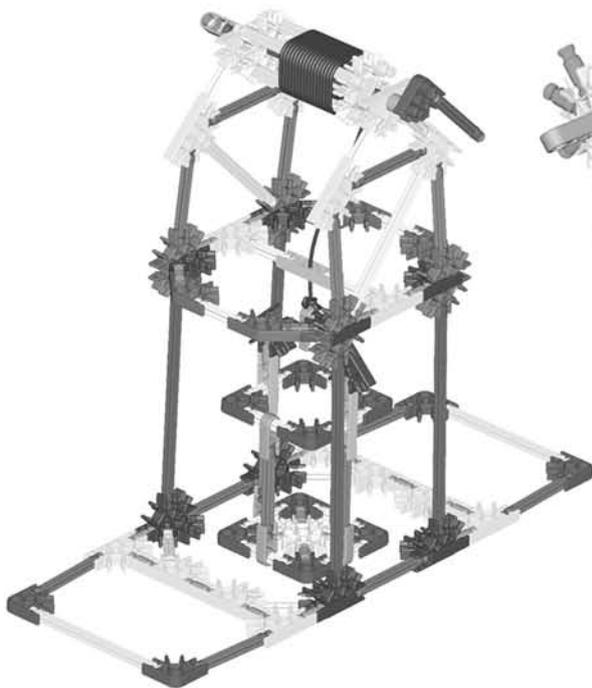
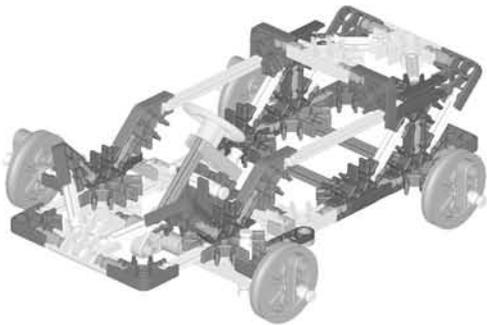
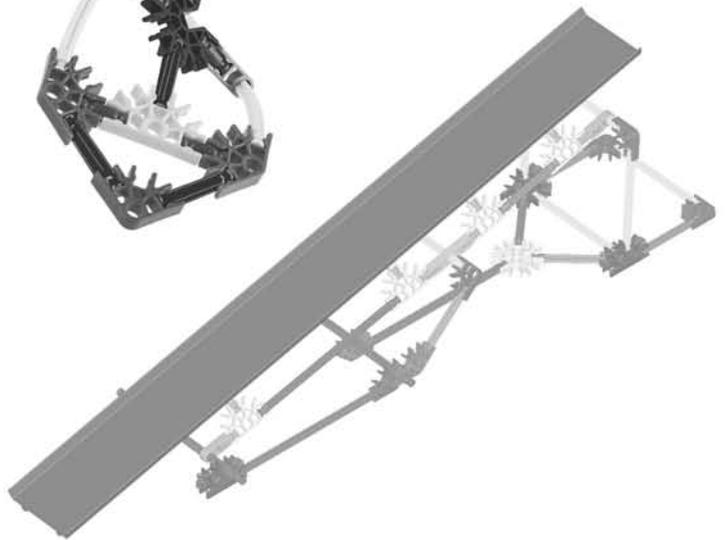
Safety is of primary concern in science and technology classrooms. It is recommended that you develop a set of rules that governs the safe, proper use of K'NEX in your classroom. Safety, as it relates to the use of the elastic bands should be specifically addressed.

PARTICULAR CAUTIONS:

Children should not overstretch or overwind their elastic bands. Overstretching and overwinding can

cause the elastic band to snap and cause personal injury. Any wear and tear or deterioration of elastic bands should be reported immediately to the teacher. Teachers and children should inspect elastic bands for deterioration before each experiment.

Caution children to keep hands and hair away from all moving parts. Never put fingers in moving gears or other moving parts.



Introduction

Your K’NEX Wheels and Axles and Inclined Planes kit is part of a series called “Understanding Mechanisms”. The series has been produced to enable Key Stage 2 pupils to investigate and evaluate some familiar products, to think about how they work and to explore the mechanisms that make them work.

Understanding Mechanisms: Wheels and Axles and Inclined Planes Kit

- Developed to introduce pupils to the way wheels and axles and inclined planes have been used in the design of familiar products, this construction kit also serves to make the connection between the models the pupils have built and the science that makes them work.
- Working in pairs or small collaborative groups, the kit provides opportunities for pupils to explore winding, lifting and cutting mechanisms through the use of investigative, disassembling and evaluative activities (IDEAs) and focused practical tasks (FPTs).

Teacher Support Materials

- Developed initially for the non-specialist teacher, the materials included in the Teacher’s Guide can also be used as a resource by more experienced teachers as they develop their own lesson plans.
- Implementing the ideas and information included in the Teacher’s Guide can build your pupils’ knowledge and understanding of mechanisms, and the ways in which they can be used to make things move.
- Key background information is provided in “A Quick Guide”, while the Lesson Notes for each K’NEX model provide more detailed information and ideas for possible teaching activities. These teaching activities have been developed primarily to support the DfEE/QCA Scheme of Work for Key Stages 1 and 2 in Design and Technology and Science,

the DATA Design and Technology Primary Lesson Plans and Primary Helpsheets.

- A glossary of technical terms and scientific definitions is offered as a resource for the teacher.
- Each of the lessons can be completed in one hour but may be extended using the suggested Extension and Research Activities. Useful Internet web sites are listed to help guide the research activities. (Note: these were functioning sites at the time of going to print.)
- The teaching activities are also intended to encourage the development of key skills by providing opportunities for whole class and group discussions, observing, evaluating and recording through the use of text and drawings, working with others to solve problems and using ICT within a design and technology context.

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A Quick Guide to Wheels and Axles

The wheel and axle mechanism has been in use for about 5000 years. Many children are familiar with the **wheel and axle** as it is used in bicycles, cars and the vehicles they make themselves in Design and Technology lessons. They recognize it as something that helps other things move easily.

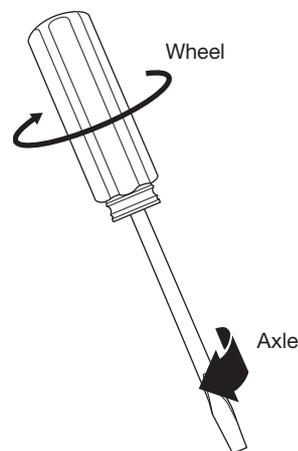
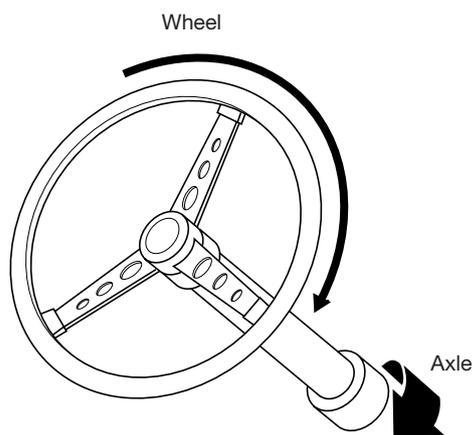
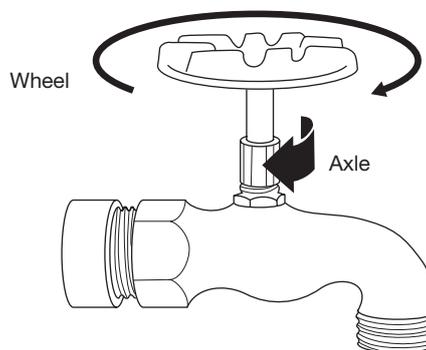
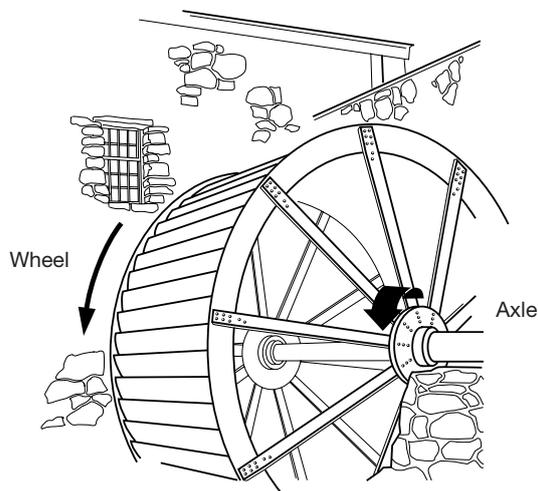
They are perhaps less familiar with the use of a wheel and axle as a **simple machine** that helps make other mechanisms work. Doorknobs, water taps, screwdrivers and handles attached to winches and other types of machinery are all examples of the wheel and axle concept in action.

A simple machine is a tool that makes it easier to do things. Using a simple machine does not change the task to be undertaken; it simply makes the job easier by changing the way it can be done.

What is a wheel and axle?

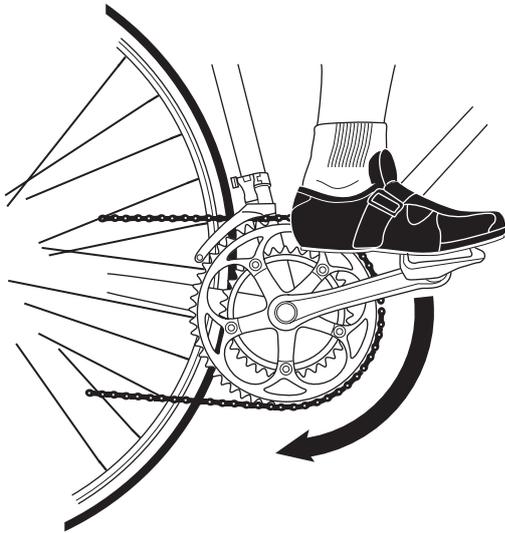
A wheel and axle is a round disk (the wheel) with a rigid rod (the axle) connected through the centre of the wheel so that when one turns, so does the other.

The wheel may be a solid, circular disk, such as a car wheel, waterwheel, doorknob, water tap, screwdriver or a gear wheel.





A wheel, however, does not have to be a circular disk; it can be the circular path outlined by a handle that turns. For example, the winch handle of the K'NEX Well model, or the peddle on a bicycle.



Key facts:

Wheels do not need to be solid disks. Wheels can be circular paths made by handles that turn.

What are wheels and axles used for?

- To transfer turning forces. For example: from a car engine to the road surface; from your hand to a door lock mechanism; from flowing water to the machinery inside a mill.
- To increase turning forces to make it easier to move objects. For example: the handle of a winch; a doorknob.
- To change the direction of motion. For example: in a winch, from the rotary motion of the turning handle to the linear motion of the object being raised or lowered.
- To make it easier to move heavy objects by reducing the effects of friction.

Wheel and axle basics:

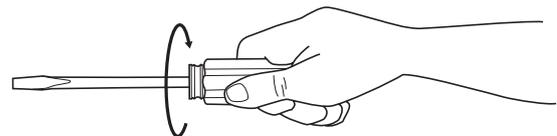
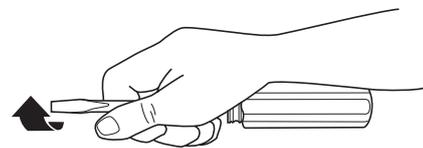
How a wheel and axle mechanism works depends on whether the wheel is turning the axle or the axle is turning the wheel.

In some cases the wheel turns the axle, as with a water wheel, doorknob and screwdriver, while in other cases the axle turns the wheel, as in a car or bicycle.

NOTE: Some wheels freely rotate on their axles and do not turn when the axle is turned. This form of wheel and axle is different from the **fixed** wheel and axle systems used to transfer forces and movement in machines and other devices. Freely rotating wheels on axles are mainly used to help reduce friction in a mechanism as, for example, in single pulleys, wheelbarrows, trolleys or conveyor systems.

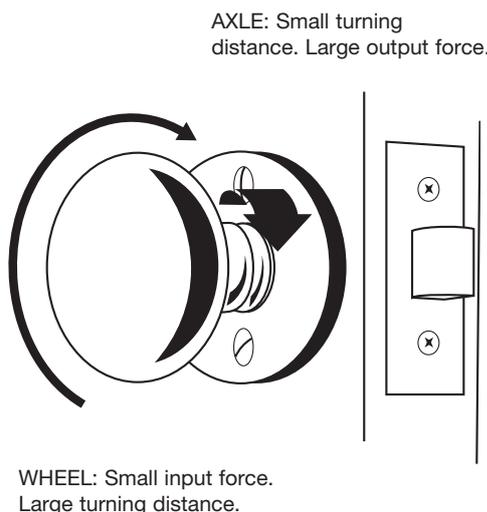
A wheel turning an axle:

A doorknob, a spanner turning a nut on a bolt, a screwdriver, a car steering wheel and a winch are all examples of a wheel turning an axle. We know from experience that a small handled screwdriver cannot be used to insert large screws because not enough turning forces can be generated. Similarly, attempting to unscrew a screw by turning the shaft (the axle) of the screwdriver is difficult. Using the wide handle (wheel) of a screwdriver, however, makes the job much easier by enabling you to generate large turning forces.



A Quick Guide to Wheels and Axles

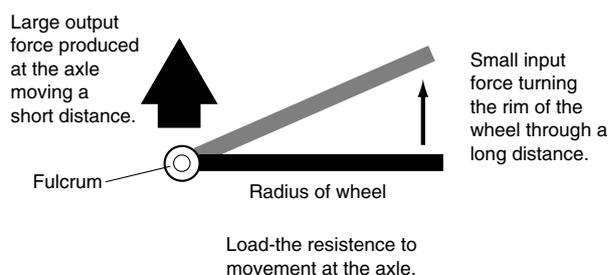
In the same way, it is virtually impossible to turn a lock mechanism by trying to turn the lock spindle itself – you cannot generate enough turning forces - but with the doorknob attached, it becomes an easier task.



Although the wheel and axle are connected and they rotate through the same angle, the actual distance moved by the rims of the door handle (a wheel) and the axle are different. Because the circumference of the wheel is larger than that of the axle, the wheel rim will move through a much greater distance than the axle.

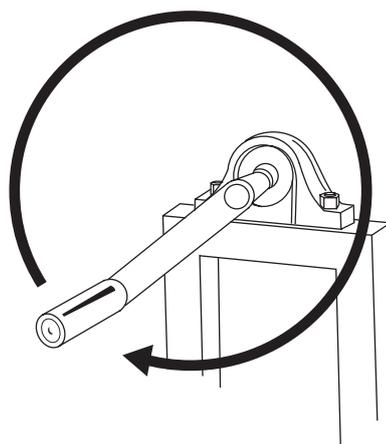
The resultant effect: **A small input force** at the door handle (a wheel) turning through a large distance produces a large output force at the axle. This causes the lock mechanism to work. The greater the radius of the wheel, the larger are the turning forces produced at the axle. In a wheel and axle mechanism, distance acts as a force multiplier. A large waterwheel generates a much greater output turning force than a small wheel turning at the same speed.

Wheel Turning an Axle



The reason for this is because a wheel and axle mechanism behaves as if it were a rotating lever, with the centre of the wheel as the fulcrum, and the wheel rim as the outer edge of the lever. Levers help to amplify input forces. The greater the distance they are applied from the fulcrum, the more the input forces are increased.

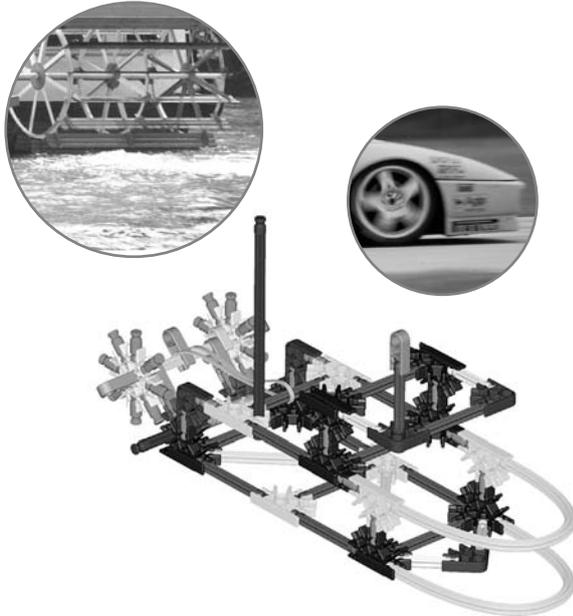
In action, this means a winch with a long handle can generate more lifting forces at its axle than one with a short handle.





An axle turning a wheel:

The context with which most people are familiar is that of a motor connected to an axle, which then turns a wheel.



To demonstrate this concept, try opening a door. A door is another example of a wheel and axle in action. The centre of the door hinge is the fulcrum, the door hinge is the axle and the door is the wheel. To open the door by pushing close to the hinge requires a lot of effort. Your hand moves slowly but the outer part of the door moves quite quickly. A small resistance against the door is enough to prevent you pushing it open. Pushing open the door a long distance from the hinge, however, requires little effort and only a large force in the opposite direction can stop you from opening it.

Key facts:

A wheel turning an axle:

- Increases the forces produced at the axle.

An axle turning a wheel:

- Increases the speed of rotation but decreases the output forces produced at the wheel rim.

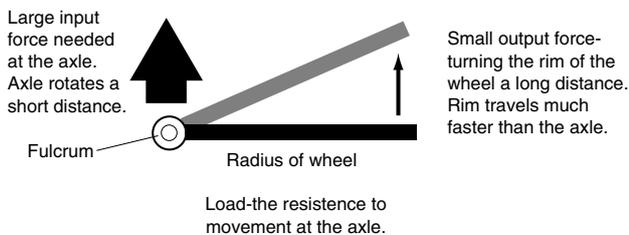
Useful Internet Web Sites:

<http://sunshine.chpc.utah.edu/javalabs/java12/machine/index.htm>

<http://www.atech.org/faculty/dunne/about/SM/INDEX.HTM>

Turning the axle will make the wheel rim, in the same amount of time, rotate through a greater distance than the axle. In other words, the wheel rim is turning faster than the axle. In this situation, a **large input force** is needed to turn the axle. The output force, however, is reduced. This situation is the reverse of a wheel turning an axle.

Axle Turning a Wheel



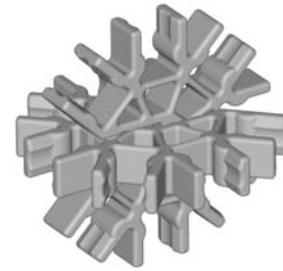
Lesson 1: Getting Started



Time: 1 hour

Learning Objectives - Children should learn:

- to assemble, join and combine materials and components
- that construction material can be used to try out ideas
- to recognise shapes and their application in structures
- to draw and label designs



Possible Teaching and Learning Activities

Introduction

This lesson provides children with the opportunity to investigate how K'NEX construction materials may be used to create different 2D and 3D shapes. It could also contribute to cross-curricular activities, including:

- (i) Mathematics: shape and space, movement and angles.
- (ii) Literacy: speaking and listening, describing observations.

Working in Groups of 2-3

- Ask the children to use the K'NEX materials in their kit to make and name different:
 - 2D shapes
 - 3D shapes – e.g. cubes, cuboids and cylinders
 - Symmetrical shapes/mirror images
- Ask the children what sorts of shapes might be used to make stable structures.
- Ask the children to look at their K'NEX components and:
 - Identify those that contain an angle of:
 - (i) 90 degrees
 - (ii) less than 90 degrees
 - (iii) more than 90 degrees
 - What sort of shapes can they make with these components?
 - Identify Connectors that allow them to build shapes containing right angles.
 - Identify Connectors that can be used to make rigid and flexible joints.
 - Identify components that can be used to make things move.

Vocabulary

dimensional, 2D, 3D, cubes, cuboids, cylinders, symmetrical, Rods, Flexi-rods, Connectors, Spacers, Hubs, Tyres, components, right angles, stable, rigid, flexible, functions

Resources

Each group of 2-3 children will need:

- 1 K'NEX Understanding Mechanisms: Wheels and Axles and Inclined Planes kit with Building Instructions booklet

Teacher's Notes

For many children, this may be their first opportunity to explore, experience and experiment with the K'NEX materials they will be using in their classroom activities. This includes learning the names of the different components and their functions.

Note: *K'NEX Rods, Flexi-rods, Connectors, Spacers, Hubs and Tyres are always capitalized.*

*The Building Instructions booklet provided in each set includes a **building tips page**, which offers guidelines for connecting the individual pieces. You may want to provide time for the children to practice connecting the different components. It is crucial that they grasp the building concept at this stage so that frustrations are avoided later.*

Provide some basic guidelines for maintaining all the pieces in the set for future use. At least 5 minutes will be needed at the end of each lesson for cleaning up the materials.

- Ask the children to:
 - Make a tall, stable structure.
 - Make a model with moving parts.
- Ask the children to make drawings of their models and to label them showing:
 - How and where they made the structure stable.
 - How their model works and the movements the model makes.
- Children may be encouraged to think about and discuss what they are doing through facilitating questions such as:
 - What does the machine do?
 - What are the functions of the moving parts?
 - How are the moving parts connected or how do they make other parts move?
 - What are the moving parts called?
 - What types of movements do the moving parts make?

Plenary session

- Choose a range of models that may be shared with the class.
- Possible questions to ask:
 - How did you make this?
 - Were any parts of the model difficult to make?
 - What parts of your model are you pleased with and why?
 - What shapes did you use in your model? Why?
 - How stable is your model? How did you test your model?
 - What movements were you trying to make and how did you make them work?
 - What components did you use to make the movements?
 - What other types of machines have you seen in which these components were used and what did the machines do?
 - What would you do differently next time?

Teacher's Notes

Using labelled drawings is an important communication skill that needs to be learnt. Emphasize to the children that it is not important for their drawing to look exactly like the K'NEX or any other machine they are investigating. It is more important for their drawing to show how the machine works. For example, they should show how the moving parts connect to each other.

Interpreting 2D drawings to construct 3D models is an important skill to be learnt and from the outset children should be asked to say what movements/functions their model will perform before they build and investigate the actual mechanisms.



Lesson 2: The Well



Time: 2.5 hours

The lesson could be divided into two separate activities:
Part 1: Investigating how a lifting mechanism works (1 hour).
Part 2: Investigating the forces used in lifting – more suitable for Year 5 and 6 pupils (1.5 hours).

Learning Objectives - Children should learn:

- to investigate and disassemble products in order to learn how they work
- about simple machines that make it easier to do things
- to relate science to the ways familiar machines work
- to communicate information about products and mechanisms through labelled drawings



Part 1: Investigating How a Lifting Mechanism Works

Possible Teaching and Learning Activities

Introduction

This lesson may be used to support the QCA/DfES scheme of work Exemplar Materials for:

Design and Technology Unit

- **2C: Winding Up**

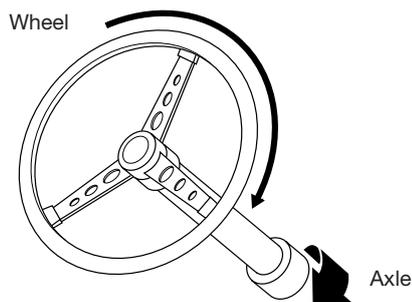
Science Units

- **1E: Pushes and Pulls**
- **2C: Forces and Movement**

Some children's stories and nursery rhymes, such as "Ding Dong Bell" and "Jack and Jill", provide familiar contexts within which to introduce the lesson, especially for younger children.

Whole Class

- Use a K'NEX Well model to demonstrate and discuss how the model's mechanism works. This activity offers you the opportunity to introduce the vocabulary the children should use later when describing their own observations. Alternatively, ask the children to describe the mechanism and then formalize or clarify their operational definitions. Vocabulary words: **axle, wheel, handle or winder.**
- Draw a labelled diagram on the chalkboard to identify the parts of a wheel and axle. (See diagram below.)



Vocabulary

wheel, axle, winder, handle, raise, lower, up, down, turn, rotate, winding, mechanism, lever, faster, slower, compare, because, long, short, longest, shortest

Resources

Each group of 2-3 children will need:

- 1 K'NEX Understanding Mechanisms: Wheels and Axles and Inclined Planes kit and Building Instructions booklet
- Felt-tipped pen
- Paper cup
- 200 gram masses
- Broom handle/30mm dowelling

You will need:

- A completed K'NEX well model
- Pictures and examples of different kinds of wheels and axles such as a cotton reel with a pencil inserted into its centre hole; a door knob; a screwdriver

Teacher's Notes

*You may find it useful to create a **word board** with the words and technical vocabulary written on cards, possibly with a simple description on the reverse side to act as an 'aide memoire' for the children.*



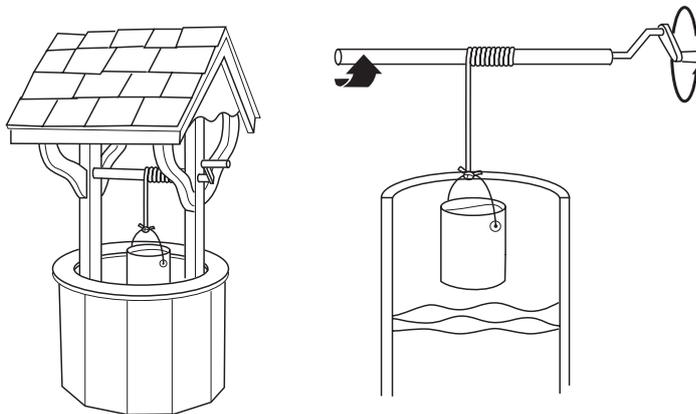
Whole Class

- Talk about how the well winding mechanism has an axle that is turned by a wheel – the handle.
- Ask the children to think of examples of machines they know that use wheels and axles. Provide pictures and examples.
- Ask the children to imagine that they are turning a large handle in the air in front of them. Ask them what is the shape they have traced.

Let's Investigate!

Working in Groups of 2-3

- Distribute a K'NEX Wheels & Axles and Inclined Planes building kit to each group.
- Explain that they will build the model of a well in which a wheel and axle system is used to raise and lower a bucket.
- Ask the children to build their K'NEX Well (Pages 2-3 of the Building Instructions booklet). Allow about 15 to 20 minutes building time. If time is a concern, ask the children to divide up the building process. One child, for example, can build Steps 1-3 and the other, Steps 4-7.
- Ask the children to identify the wheel and axle in their machine.
- Allow them some time to investigate how the mechanism works by lifting the paper cup and 200g mass placed in the 'bucket.'



- Ask the children to observe what happens when they make the winding mechanism work.
- * **Describe the shape made by the turning handle.**
- * **In which direction does the 'bucket' move when the handle is turned first in one direction and then in the opposite direction?**

Teacher's Notes

Children will be familiar with wheels through Design and Technology Unit 2A: Vehicles, through playing with toys, pushing trolleys or journey's in cars and they may have an understanding of the terms 'wheels and axles'. They may not, however, recognise that the circular (rotary) movement made by a handle when it turns is the same movement as that made by a wheel. It may be necessary to explain to the children that wheels are not necessarily solid circles but that they can also be the circular shape traced out by a handle. A handle could be described as a 'one spoke' wheel.

It is important to note there is a difference between the wheel and axle used in trolleys, prams and wheelbarrows etc. and a wheel and axle mechanism. In wheelbarrows and trolleys, the wheel and axle has only one main function and that is to overcome, or reduce, friction. When the wheel turns, it turns alone - the axle is stationary. The wheel and axle used in mechanisms such as a waterwheel or the winch of a well, enables you to transmit forces. For example, in the well winding mechanism, the use of a long handle makes it much easier for you to lift a heavy load. At the same time, it converts the rotary motion of the handle into a vertical, linear movement for the object being raised.

If time allows, children could be encouraged to carry out some research using the school library or the Internet to find other examples of winding mechanisms.

You may find it useful to write the activities on the board as a reference for later class discussions.

- * **A circle.**
- * **Up and down; in a straight line.**

Lesson 2: The Well

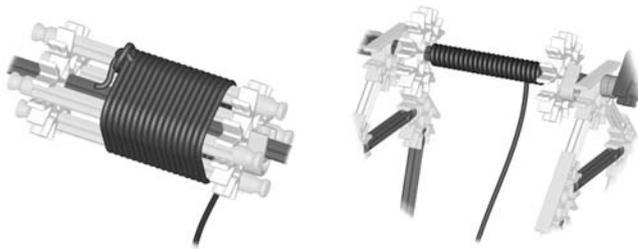
* How many turns of the handle are needed to raise the bucket from the floor?

- Ask each group to record their observations, to draw and label the different parts of their K'NEX Well mechanism and to explain how it works.

Write the children's results on the board and discuss their findings.

Whole Class

- Ask the children to look at the drawing of the 'big axle' and 'small axle' on Page 3 of the K'NEX Building Instructions booklet. Do they think the differences in axle size might make it easier or harder to raise the bucket containing the 200g mass?
- Ask the children to explain their answers using 'because...'



Working in Groups of 2-3

Investigating the answers:

- Ask the children to repeat their earlier activity using the 'big axle.' They should begin with the blue Rod facing up and they should turn the wheel all the way around to lift the bucket. Ask them to record:
 - The number of turns of the handle that are needed to raise the 'bucket' from the floor. Each time the blue Rod faces up, one full turn of the handle has been completed.
 - How fast the bucket rises.
 - How easy or difficult it is to turn the handle.
- Repeat the investigation using the 'small' axle. They should remove the yellow Rods from the axle and attach the string to the red Rod that now forms the axle.

Whole Class

- Discuss with the class whether or not their initial thoughts were right.
- Ask children from different groups to present their findings. Encourage them to talk about and discuss their results.

* Whatever the children count.

Teacher's Notes

The K'NEX Well model works best if placed between two desks so the children can raise or lower the bucket from the floor. A book should be placed on each side of the model's base to hold it firmly in place. (See Page 3 of the Building Instructions.)

You may find it useful to write the activities on the board as a reference for later class discussions.

Instead of talking about big and small axles you may wish to introduce other ways of describing relative sizes of circles using terms such as radius, diameter and circumference, if appropriate. The children should have discovered that with the larger axle it takes about 5-7 turns of the handle to raise the bucket from the floor to the desktop.

With the small axle it takes about 20 – 22 turns to raise the 'bucket' to the desktop. Although many more turns of the handle were required, using the small axle makes it easier to raise the 'bucket'.



Optional Activity

- Ask the children to count the number of turns of the handle that are needed to raise the 'bucket' 10 cm. They can calculate and compare the distance the bucket is raised after one turn of the big and small handles.
- If the axles are circular in section, this distance will also be the axle circumference.

Part 2: Investigating the Forces Used in Lifting (More suitable for Year 5 and 6 pupils)

Whole Class

- Ask the children to consider if using a long handle rather than a short handle will make it easier to raise a load.
- Ask the children to explain their answers using 'because...'

Let's Investigate!

Working in Groups of 2-3

Investigating the answers:

- * **Suggest that they change the size of the handle by using longer and shorter Rods and then repeat the experiment.**
- * **How do the other Rods compare with the blue Rod?**
- * **Do they make it easier or harder to lift the bucket?**
- * **What is the heaviest load each handle can raise to the desktop from the floor?**

Levers in action

When levers move they pivot around a fixed point – the fulcrum. Some levers can be made to rotate a full circle, as with spanners, wrenches and wheels. The well handle works like a rotating lever whose fulcrum is the centre of the axle. A long lever makes it easier to move a load because the effort needed is applied a long way from the fulcrum. Long handles make it easier to lift heavy loads because they need less effort to turn them.

Teacher's Notes

In both cases the job done is the same - the 'bucket' has been raised to the same height. With the larger axle, the 'bucket' will be raised faster, needs fewer turns of the handle and requires more effort. With the small axle, the 'bucket' will be raised slowly, needs many more turns of the handle but requires much less effort.

The activity is best carried out using the 'big axle' version of the K'NEX Well model. The handle can be lengthened or shortened by using different coloured connecting Rods.

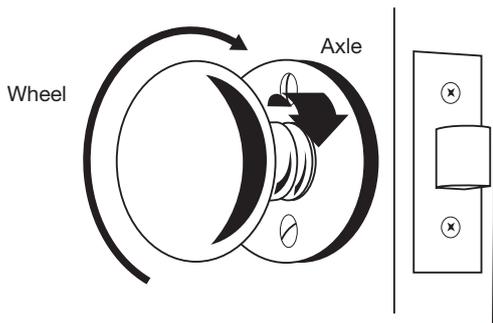
The children should note that the longest handle makes it much easier to raise a weighted 'bucket' and could be used for the heaviest loads. They may even find that when using the shortest handle, or when simply trying to turn the axle on its own without a handle attached, it may not be possible to raise the 'bucket' from the floor, no matter how hard they try to turn it.

See: A Quick Guide to Wheels and Axles for additional information.

Lesson 2: The Well

Whole Class

- Discuss how the handle of the well is an example of a wheel. The handle turns in a circle, just like the rim of a bicycle or any other wheel with which they may be familiar. It is like a bicycle wheel with only one spoke.
- Talk about other example of 'wheels and axles' that the children may not immediately recognise. Turning these wheels and axles usually makes something else move. For example: a doorknob, a screwdriver, a steering wheel and a spanner turning a nut.

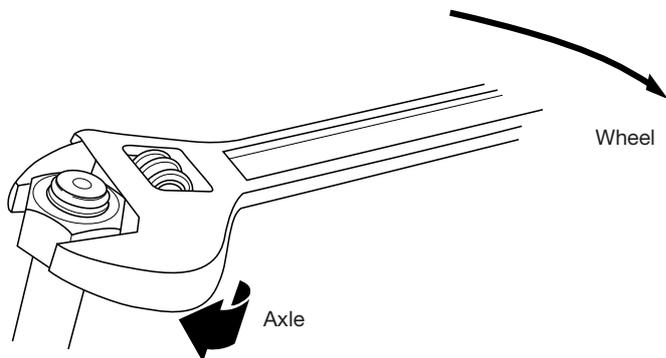


WHEEL: Input Force

- Small input force
- Large turning distance

AXLE: Output Force

- Small turning distance
- Large output force



- In a screwdriver, the handle is the wheel and the shaft that connects to the screw is the axle. It is much easier to insert a screw with a wide handled screwdriver than with a narrow one.

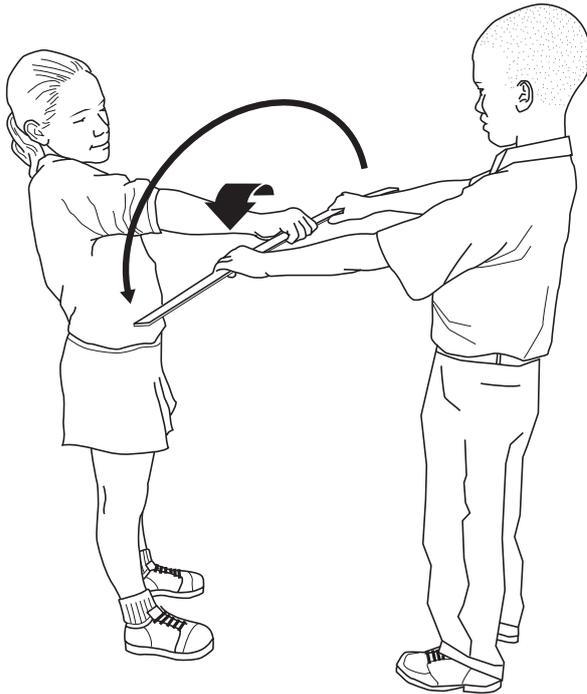
Extension Activity 1/Optional Activity Working in Pairs

We would like to thank Susan Frazier and the directors of the SMILE program at the Illinois Institute of Technology for granting us their permission to include the following activity. ©1990. [Please visit <http://www.iit.edu/~smile/ph9005.html> for further information.]

This activity allows the children to experience the forces involved in a turning wheel and axle for themselves.

Teacher's Notes

See: *A Quick Guide to Wheels and Axles* for additional information.

**Resources:**

60cm length of 30mm dowelling
or a broom handle.

- Ask one member of the pair (A) to extend one arm and firmly grasp the centre of the dowelling or ruler. The other member (B) places his/her hands on either side of A's hand and tries to turn the length of dowelling while A tries to stop the turning movement.
- How difficult was it for A to stop the turning movement? How easy was it for B to turn it?
- Child B now places his/her hands approximately 20cm from A's hand and repeats the action.
- How difficult is it for A to stop the movement?
- Child B should repeatedly move his/her hands further away from A until the dowelling turns easily.
- The children change positions and roles and repeat the activity.

Whole Class

Discuss the children's experiences.

Working in Pairs

- Ask the children to try the exercise again, only this time A, the axle, tries to turn the wheel and B tries to prevent this.

Teacher's Notes

In this example, A represents the axle and B is the handle (wheel). When A and B are close together, it is difficult for B to turn the axle. However, the further B's hands are placed from the axle, the easier it is for B to turn it. Just like a lever in action.

In the reverse situation, when A (the axle) is being turned, it is very difficult for A to make the wheel turn - a large input turning force must be applied to the axle to enable the large wheel to be turned.

Lesson 2: The Well

Teacher's Notes

When making a powered vehicle, as in Design and Technology Units 6C: Fairground and 6D: Controllable Vehicles or in any model they may make that is driven by an electric motor, children often try to connect a motor with a small axle to a large wheel and are surprised when their model does not run when placed on a surface. The small amount of friction between the wheels and the surface is enough to prevent the vehicle moving. The electric motor cannot generate enough turning forces to turn the large wheel.

Teacher's Notes

To promote the wider use and application of ICT skills and practices, the children's models and work could be recorded using a digital camera.

Design Task

Working in Groups of 2-3

- Ask the children to create a mechanism for raising and lowering the spider for the nursery rhyme, Little Miss Muffet. The spider should be able to move slowly up and down.
- Discuss:
 - What materials the children may need to use.
 - How the mechanism will work.
 - How they will add the characters from the story to make it look more realistic.
 - The tasks people will carry out to create the characters and mechanism.
- They should be encouraged to make a labelled drawing of their design and write a description of how their design works before starting construction.

Plenary

Select some models to share with the class and ask the children to describe:

- The reasons behind their design. "We did this because..."
- Why their design works well.
- What parts of their design they are pleased with.
- What tests they carried out to evaluate their design against the design brief.

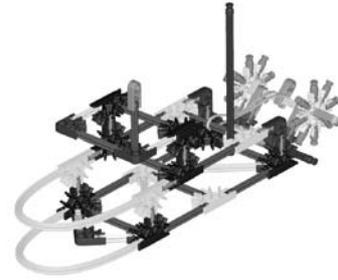
Lesson 3: The Paddle-boat



Time: 1 hour

Learning Objectives - Children should learn:

- to investigate and disassemble products in order to learn how they work
- how to convert rotary motion into linear motion
- to communicate information about products and mechanisms through labelled drawings



Possible Teaching and Learning Activities

Whole class

- Review the outcomes of the previous lesson in which it was found that a wheel and axle mechanism can be used in two ways.
 1. A large wheel turns an axle, as in a water wheel or the winding mechanism of a well.
 2. A small axle turns a large wheel, as in a car.
- Explain that in this lesson the children will investigate how paddle-boats use an axle turning a large wheel to drive them through the water.
- Children may be familiar with steam paddle-boats from films, or perhaps their own experiences of seeing or using pedal powered boats – **pedalos** - while on holiday. The method of propulsion is the same: the paddles push against the water, driving the boat forward.
- Swimming uses the same principle - the children push against the water using their arms and feet. Flippers allow them to swim faster but it is harder to push against the water.



Vocabulary

wheel, axle, turn, rotate, winding, mechanism, faster, slower, compare, friction, resistance, larger, smaller, design

Resources

Each group of 2-3 children will need:

- 1 K'NEX Understanding Mechanisms: Wheels and Axles and Inclined Planes kit with Building Instructions booklet
- Heavy-duty elastic bands
- Small blocks of wood or expanded polystyrene foam to help the model float (2 per model)
- Sheet plastic/card
- Cling film or aluminium foil
- Scissors
- Ruler and pencil
- Adhesive tape
- Container or sink filled with water to test paddle-boats

Useful Internet Web Sites:

www.ulster.net/hrmm/steamboats/fulton.html: Reviews the historical development of steamboats from the early 19th Century.

www.museum.state.il.us/: Go to: 'Search this web site.' Enter: "steamboats and paddle boats" and follow simple links. A useful source of historical photographs.

www.pics.tech4learning.com/: Go to: 'Transportation/boats' for free photographs of paddles in action.

Lesson 3: The Paddle-boat

Working in Groups of 2-3

- Ask each group to build their K'NEX Paddle-boat model and allow them some time to investigate how it works.
- Explain that they should wind the elastic band around the axle using the grey end Connector and then release it to observe how the paddle mechanism works. You might suggest they think about the following:
 - What is the function of the machine?
 - What are the functions of the moving parts?
 - How are the moving parts made to move?
 - Identify and name the wheel and axle.
 - How quickly does the wheel move when released?

Whole Class

Using the K'NEX Paddle-boat as an example, demonstrate on the board how to make simple labelled drawings. Include the use of arrows to show the direction of movement.

Working in Groups of 2 - 3

- Ask the children to record their observations and results, using labelled drawings and notes. Arrows should be included to show the direction of movement. The children should be encouraged to use the correct vocabulary and terminology as they describe how the mechanism works.

Whole Class

- Talk about the children's observations. Encourage them to use their K'NEX models to demonstrate their explanations using the correct technical vocabulary.

*** What provided the force to turn the wheel and axle?**

Teacher's Notes

This activity involves children stretching an elastic band. There is a need to carry out a risk assessment for the activity. See: Safety Information at the beginning of this Guide. Children should be warned about the dangers of overstretching an elastic band when investigating their model.

See: A Quick Guide to Wheels and Axles for additional information.

Children's models and work could be recorded using a digital camera so enabling the wider use of ICT skills and practices.

*** The energy stored in the stretched elastic band.**

Discuss the difference between the speed at which the wheels move when the elastic band is being wound up compared to when it is released.

The children should notice that it takes a lot of effort to wind the elastic band using the axle and the paddle-wheels rotate slowly. Once released, however, the paddle-wheels spin very quickly. The elastic band serves as a "motor" that provides the turning forces (effort) to turn the axle and hence the wheel.



Some children may find it difficult to understand how the paddle-wheel can spin faster than the axle to which it is connected. The children will reason that because they are connected, they must turn at the same speed.

Try this!

- Ask two children to hold on to either end of a long pole or broom handle. Both should face in the same direction. One child is the axle and the other is the outer edge of the paddle wheel. Ask them to turn in a circle. As they turn, the child who is the axle must turn slowly while their partner at the outer edge must move quickly to keep up.

Let's Investigate -

How well does the paddle-boat work in water?

Whole Class

- Explain to the children that they will now test how well their elastic band 'engine' and paddle design works. They can use elastic bands to attach blocks of wood or expanded polystyrene to their K'NEX model to help it float. Alternatively, they can cover the hull with aluminium foil or cling film.

Working in Groups of 2-3 / Demonstration

- If possible, each group should have the opportunity to test how well, or not, their paddle-boat moves through the water.
- Discuss how improvements could be made to the paddle-wheel design to help make the paddle-boat move faster through the water.
- Provide card, cling film (or sheet plastic), scissors and a ruler for making paddles.

Teacher's Notes

You may find it useful to create a word wall showing the range of words and terminology the children may need as they discuss their investigations and findings, and for when they make labelled drawings and write descriptions. Words could be written on cards, possibly with simple descriptors on the reverse side

See: Key Technical Terms and Scientific Definitions for additional information.

Depending on the time available, each group might test only one sized paddle (5 cm x 5 cm), or a range of different sized paddles attached to each of the green rods on the paddle-wheel, to find the best sized paddle to meet the design brief.

Alternatively, different groups could be given a specific paddle size to test. Paddle sizes ranging from 2 x 2 cm to 5 x 5 cm + could be tried.

The class could then be asked compare and evaluate their results.

Lesson 3: The Paddle-boat

Key Fact

- To turn a large wheel, very large turning forces must be applied to the axle.

Plenary

Ask the children to discuss and explain their observations and their recommendations for the fastest paddle design.

Teacher's Notes

Some children may suggest that the larger paddles will work best because they will move the fastest or simply because they are the biggest.

As they will have discovered earlier, however, in order to turn a large wheel, very large turning forces will be needed to turn the axle. Their elastic band 'engine' may not be able to deliver enough turning forces to overcome the resistance of the water against which the paddles must push.

The larger paddle-wheel may move very slowly at first and then move faster as the initial resistance to the movement (friction) is overcome.

Smaller paddles will move more easily, but not as quickly, or push as much water, as the larger paddle-wheels.

Children often make a similar error when designing and making powered vehicles. They frequently use large wheels and/or connect a large pulley or wheel directly to a motor. They are surprised that the vehicle will not move when put on a surface despite the fact the wheels turn when they hold it in their hands.

This is because a small resistance applied to the wheel, such as the friction between the wheel and the desk, (or in the case of their boat, the resistance of the water), is enough to cause the motor to stall. With the frictional force removed, the motor can generate enough force to turn the wheel.

Lesson 4: The Steering Wheel



Time: 1.5 hours

Learning Objectives - Children should learn:

- to investigate and disassemble products in order to learn how they work
- about simple machines that make it easier to do things
- to relate science to the ways familiar machines work
- to communicate information about products and mechanisms through labelled drawings



Possible Teaching and Learning Activities

Introduction

This lesson may be used to support the QCA/DfES Scheme of Work Exemplar Materials for:

Design and Technology Unit

- **6 D: Controllable Vehicles.**

Whole Class

- Based on the children's findings from earlier lessons, review how a wheel and axle mechanism can be used in two different ways:
 1. In the K'NEX Well model, a large wheel - the handle - was used to turn a small axle. This mechanism required a small effort to produce an increase in turning forces at the axle and so made the job of lifting a heavy object easier.
 2. In the K'NEX Paddleboat model, a small axle was used to turn a large wheel. This mechanism needed a large effort at the axle but only produced small forces at the wheel rim. The wheel rim, however, moved much faster than the axle.
- Explain to the children how, in this lesson, they will investigate the way in which a wheel and axle mechanism can be used to help control the direction in which a vehicle travels.
- Talk about how different types of transport can be steered. For example:
 - Boats and aircraft
 - Bicycles and trolleys
 - Cars, trucks and buses
 - Vehicles they have made themselves
 - Tracked vehicles

Vocabulary

wheel, axle, linkage, parallel linkage, parallelogram, steering, mechanism, faster, slower, diameter, modify

Resources

Each group of 2-3 children will need:

- 1 K'NEX Understanding Mechanisms: Wheels and Axles and Inclined Planes kit with Building Instructions booklet.

Useful Internet Web Sites:

www.howstuffworks.com/steering/
Demonstrates how a car's steering system works. Good background information for teachers.

For Reference

Macaulay, David. 'The Way Things Work.' Houghton Mifflin Company. 1988. Either the book or CD ROM is an excellent resource.

- Rudders
- Pivots
- Steering Wheels
- Answers will vary
- Two motors, using forward and reverse gears

If time permits, allow the children to use the school library or the Internet to research these different methods of controlling the direction of movement. Encourage them to find pictures of different types of steering mechanisms and create a wall display.

Lesson 4: The Steering Wheel

Let's Investigate!

Working in Groups of 2-3

- Ask each group to build their K'NEX car model (Pages 6-8 of the Building Instructions booklet). Remind the children that there are 3 pages of building instructions for this model. Limit their building time to 15 – 20 minutes but ensure that all the groups have time to observe and investigate the steering mechanism as they push their vehicles along a desktop or the floor.
- To reduce building time, ask the children to divide the building task between them. If they are working in pairs, for example, one pupil should build Steps 1-5 and the other, Steps 6-10 before completing the model at Step 11.
- The children should discuss and record how the mechanism works.
- The following questions may help guide their investigation. You may find it useful to write the questions on the board as a reference for later class discussions.

* **Identify the wheel and the axle. What is their function in the steering mechanism?**

* **How does the wheel and axle mechanism cause the front wheels of the vehicle to turn?**

* **Is this an example of a wheel turning an axle or an axle turning a wheel?**

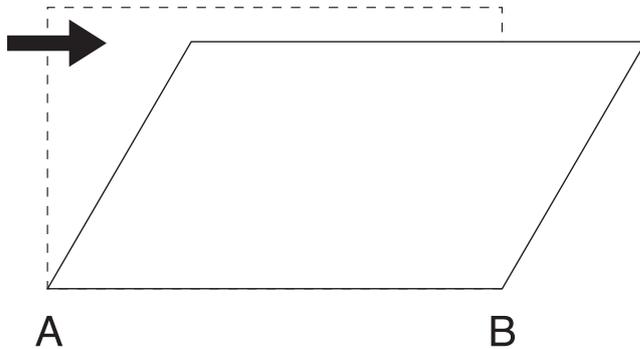
* **Is it easier to turn the steering mechanism with, or without, the steering wheel attached?**

* **The yellow steering wheel and the blue Rod. The wheel is turned to make the axle rotate.**

* **The steering wheel does not directly turn the wheels of the vehicle. It turns the steering column – axle. The axle has an orange Connector attached to it and this pivots when the steering wheel turns. A white Rod connects the orange Connector to the steering mechanism. When the steering wheel is turned, the steering mechanism pivots left and right.**

* **A wheel is turning an axle.**

* **It is easier to turn with the steering wheel attached. The steering wheel has a larger diameter than the axle and so helps to increase turning forces.**



Principle of Parallel Linkage

Extension Activity

- Ask the children to investigate the following questions, using the school library and Internet:
 - Do all vehicles have the same sized steering wheels?
 - How does the size of the steering wheel relate to the job a vehicle does? Consider, for example, a family car, a lorry, a bus, and a Formula 1 racing or sports car.



Teacher's Notes

The steering mechanism is an example of a linkage mechanism. Linkage mechanisms allow (i) forces and movements to be transferred, (ii) the direction of a force to be changed, or (iii) things to be moved in a particular way.

Calliper brakes on bicycles, treadle sewing machines and toolbox drawers that stay level when opened are examples of linkages.

The K'NEX car steering linkage is based on a parallelogram. A parallelogram linkage can be used to make two sides move together and stay parallel to each other while one side (AB) remains fixed. See diagram: Principle of Parallel Linkage.

In the K'NEX Car model AB is the front section of the car, (Building Step 6), located between the two upright white Rods.

Lorries and buses are large, heavy vehicles with large, heavy wheels and steering mechanisms. Turning the wheels on such vehicles requires a great amount of effort. The steering wheel for this type of vehicle, therefore, will have a large diameter because this needs less effort to turn than a wheel with a small diameter. In order to turn the wheels of the vehicle, however, the large steering wheel must be turned through a greater distance than would a smaller one. Lorries and buses, therefore, tend to make turns more slowly than do smaller vehicles. There is also a safety issue involved here – these types of vehicles may become unstable if they try to turn corners too quickly.

Lesson 4: The Steering Wheel



Teacher's Notes

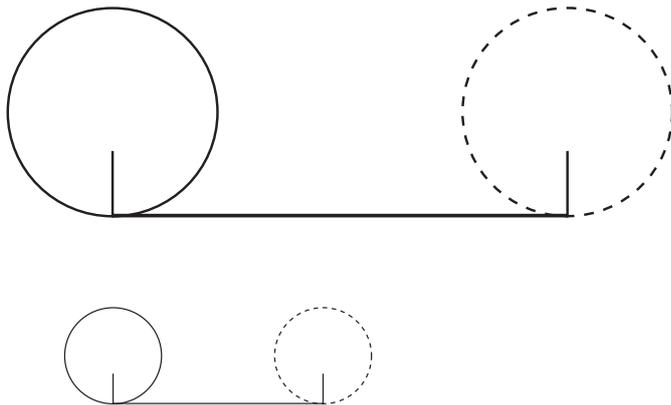
Formula 1 racing cars travel at high speeds and their steering needs to respond very quickly. At these high speeds, a smaller steering wheel gives the driver much greater control over the car's direction of movement through the use of rapid, small hand movements. More effort is needed, however, to turn a small steering wheel compared to a larger one.

Steering wheels for family cars will fall between these two sizes.

To help explain how a larger steering wheel must turn through a greater distance than a small steering wheel...

• Try this!

Using dowelling or a wheel, ask the children to make a mark at one point on its circumference. Place the dowelling or wheel on a piece of A4 paper, mark the start point on the paper, roll it until the mark touches the paper again and then measure the distance between the two marks. Repeat with a different diameter dowelling or wheel.



Plenary

Talk about how the design of steering wheels must take into account their intended purpose. Ask the children to explain the function of the mechanism they have investigated and how they might modify the design if it was to be used for a racing car or a large truck.

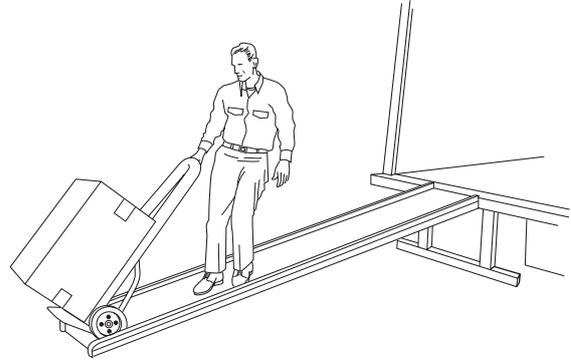
A Quick Guide to Inclined Planes

We know from our experience of walking up hills that it needs less effort to walk up a gentle slope than a steep one. In the end, however, both routes will take us to the top and we will have climbed the same vertical distance. The difference lies in the fact that one route will cover a longer distance than the other, but it will appear to be easier to accomplish.



The same principle is used in a number of different contexts. Ramps, for example, can be used to load heavy objects into lorries or to allow wheel chairs to avoid stairs.

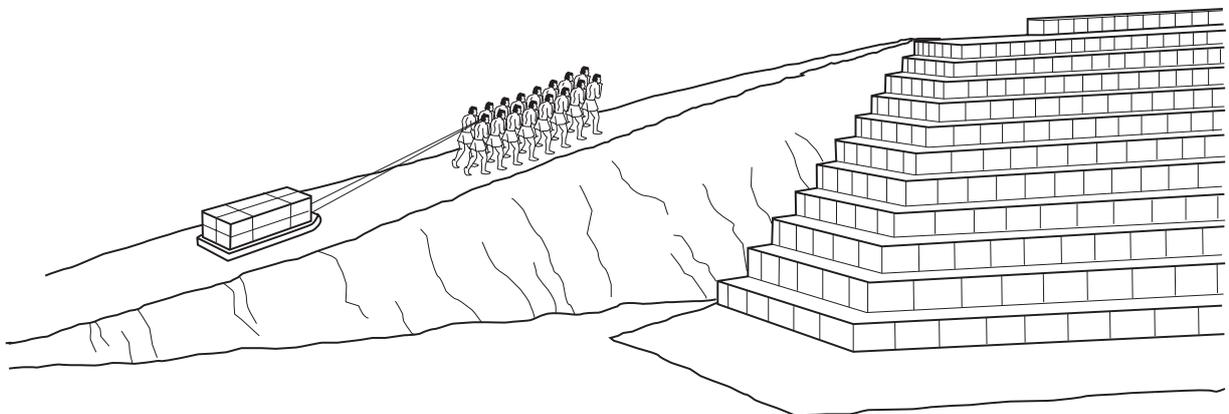
Rather than try to lift the load vertically onto the back of the lorry, it is much easier to move it up a ramp.



Ramps and gentle slopes are examples of a simple machine called an inclined plane.

A simple machine is a tool that makes it easier to do things. Using a simple machine does not change the task to be done; it simply makes the job easier by changing the way it can be done. As we noted earlier, to reach the top of a hill you can take a short, direct route up a steep slope that requires a lot of effort on your part, or you can stroll up a much longer, but gentler route. The second option is the basis of the inclined plane.

Using ramps to move and raise heavy objects is not new. The ancient Egyptians probably used ramps to build their temples and pyramids.



A Quick Guide to Inclined Planes

What does an inclined plane do?

Inclined planes are used to lift a load through a vertical distance. A load can be lifted vertically upwards but this will need an effort at least equal to the weight of the load. An inclined plane makes the job easier.

Other simple machines such as levers and pulleys could possibly be used to do this task. Inclined planes simply give engineers another tool to use, but the choice of tool to be used depends on the job to be done.



Consider the practical problem of raising a heavy stone block, weighing several tonnes, to the top of a pyramid. An inclined plane was the only practical tool that could have been used by the ancient Egyptian engineers.

What are inclined planes used for?

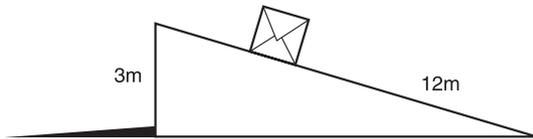
Not all inclined planes come as giant structures. Their use can be found in many familiar tools even though, at first sight, some of these tools do not appear to look like an 'inclined plane'. Examples include: loading ramps, stairs, ladders, the cutting blades of an axe, chisel and knife, spiral staircases, screws, nuts and bolts, screw-threads in water taps, bottle tops, car jacks, bench vices, door stops, ploughs and zip fasteners.



Inclined planes can also be used for controlling the rate of descent of an object from a height. The fastest way to descend from one floor to another is to go straight down using, for example, a fireman's pole. A slower, more controlled descent is achieved by using an inclined plane – the stairs. The gentler the slope, the longer the distance to travel and the longer the time it takes to negotiate the vertical change in height.

How does an inclined plane work?

Look at the example in the diagram below.

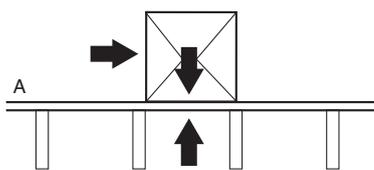


An object must be moved to a vertical height of 3m. It can be lifted the 3m vertically but this would need an effort at least equal to the weight of the load.

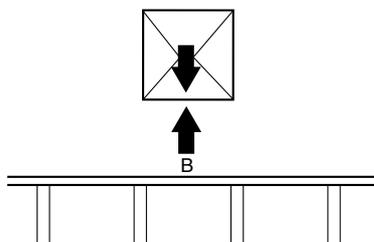
If the load is moved up the inclined plane, the distance the load will travel will be 12m but the effort needed to move it will only be 1/4 of that needed to lift it vertically. That effort, however, must be sustained over a longer distance - 12m compared to 3m.

In both cases the load has been raised to a height of 3m; only the way in which it was done is different.

Why does it take less effort to use an inclined plane?



A. Weight of load balanced by floor pushing up.

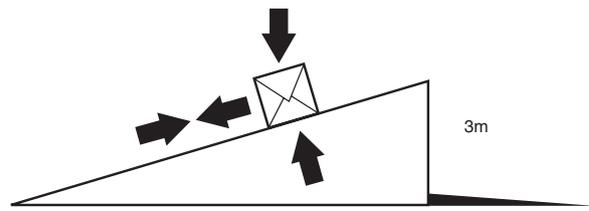


B. All the effort is expended against gravity.

When you push an object along a level surface (A) all your effort can be used to move the load through a horizontal distance. (Note: In reality, friction will come into play.)

When lifting an object vertically (B), gravity is working entirely against you. All your effort is put into lifting the object vertically, all the time working against gravity. In (A), however, the level surface balances the force of gravity for you; you contribute nothing to this effort.

Using an inclined plane (C) to raise the load 3 meters will result in the workload being shared between the surface of the slope and your effort.



C. Sharing the workload.

The gentler the slope, the greater the contribution made by the slope's surface to balancing gravity and the smaller the effort needed to counter the effect of gravity on the load. Most of your effort can then be put into moving the load along the slope. The task of lifting the load becomes easier.

The steeper the slope, the more effort you have to contribute to work against gravity, with correspondingly less effort available for moving along the slope. The task becomes harder.

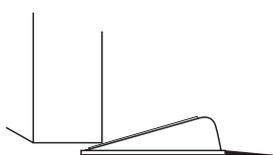
A Quick Guide to Inclined Planes

Key Facts

- An inclined plane can be used to lift loads through vertical distances.
- The longer the slope, the less effort is needed to complete the task, but the distance over which the effort must be applied is increased.
- An inclined plane is an example of a simple machine.
- A simple machine is a tool that makes it easier to do tasks by changing the way they are done. A simple machine cannot change the task itself.
- Inclined planes can also be used to control the rate of descent of an object from a height.

Different Uses of Inclined Planes

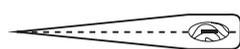
Inclined planes are found not only in ramps but also, as noted above, in smaller tools. Many cutting tools, such as knives, chisels, scissors, axes and forks use a **moving** inclined plane or **wedge**. You are probably familiar with the door wedge. Look at its shape; it is typically an inclined plane.



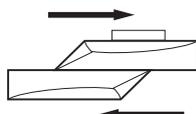
Door wedge: As the door wedge moves forwards, the slope pushes upwards against the door. Friction stops the wedge sliding backwards.



Knife blade.

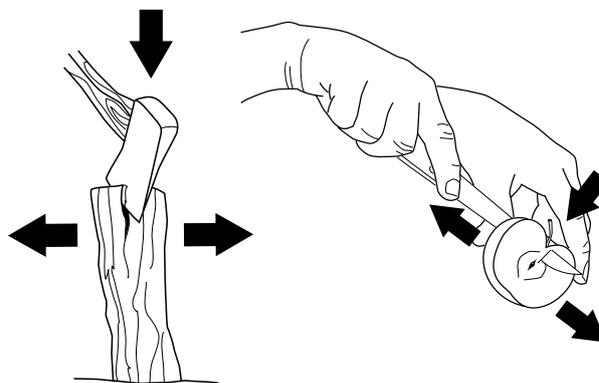


Axe head: Two inclined planes back-to-back.



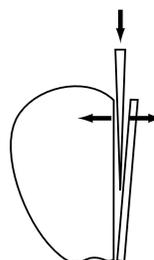
Scissors: Two inclined planes moving in opposite directions across each other.

When a wedge is pushed down into an object, the object it is pushing against is forced apart sideways in a direction that is at right angles to the movement of the wedge.

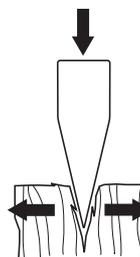


The greater the distance the wedge moves into the object, the greater are the lateral forces produced.

The wedge works in exactly the same way as a ramp but with its sharp end pointing down.



A knife is a **thin wedge** (*gentle slope*). Its action results in a small separation of the two sides of an object with a small amount of applied force.



An axe is a **fat wedge** (*steep slope*). Its action causes a large separation of the sides of the object, but this needs a large amount of applied force.



Not all inclined planes have straight edges.



Key facts:

- Wedges are moving inclined planes.
- The wedge concept is used in many cutting tools.
- The greater the distance moved by the wedge into the object being cut, the greater are the separating forces produced.
- Inclined planes can also be spirals or screws.

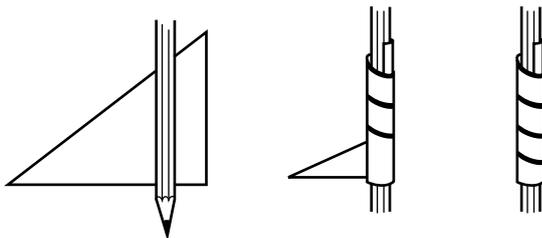
How is a spiral staircase an inclined plane?

Make a right angle triangle by folding and cutting an A5 sheet of paper across the long diagonal.

Mark the diagonal, place the marked edge **face down** on the desk and roll a pencil around the paper as shown in the diagram.

The inclined plane now forms a spiral around the pencil shaft. The same principles apply: the spiral or screw thread form helps you apply the effort force over a longer distance, so reducing the effort force needed to do a task.

This task can be climbing a flight of stairs, drilling a hole or inserting a screw into a piece of wood. The longer the slope, the greater the number of spirals, and the easier the task becomes.



Lesson 5: Ramps



Time: 1 hour

Learning Objectives - Children should learn:

- to investigate and disassemble products in order to learn how they work
- about simple machines that make it easier to do things
- to relate science to the ways familiar machines work
- to communicate information about products and mechanisms through labelled drawings



Possible Teaching and Learning Activities

Introduction

The activities in this lesson may be used to support the QCA/DfES Exemplar Materials for:

Science Units

- **2E: Forces and Movement**
- **4E: Friction**
- **6E: Balanced and Unbalanced Forces**

The K'NEX ramps could also be used in the children's experiments in the Science Unit **2E: Forces and Movement** to measure distances and make comparisons, to carry out fair tests, as well as to question and predict the behaviour of different toys rolling down ramps.



Vocabulary

ramp, inclined plane, simple machine, mechanism, force, effort, load, vertical height, distance, gentle, steep, friction, coarse surface, smooth surface, lubricant, force meter, Newton

Resources

Each group of 2-3 children will need:

- 1 K'NEX Understanding Mechanisms: Wheels and Axles and Inclined Planes kit with Building Instructions booklet
- Felt-tipped pen
- Heavy-duty elastic bands
- Rulers/tape measures
- 400 gram masses or other heavy objects
- 10N Force meter

Useful Internet Web Sites

<http://www.smartown.com/sp2000/machines2000/main.htm>

<http://edheads.org/activities/simple-machines/index.htm>

<http://thinkquest.org/sitemap.html>
(Search >Library for pages on Simple Machines.)

These web sites contain general information on Simple Machines but there are specific references to inclined planes. <http://edheads.org> is a particularly good site with animated contexts for testing children's understanding of key concepts.



Whole Class

- Ask the children to talk about how they might move themselves or heavy objects from a low level to a higher level.

They may discuss, for example:

- * **How people reach something much taller than themselves in a building.**
- * **How people in wheel chairs enter and exit buildings with high steps.**
- * **How the ancient Egyptians moved heavy blocks to build the pyramids.**



- * **Stairs and ladders.**
- * **Ramps.**
- * **They probably used ramps.**

- Explain how ramps, stairs and ladders are 'tools' that are used to make it easier to move heavy objects and people from one level to another. You may want to sketch Fig. 1 on the board to clarify the discussion.
- Discuss how ladders have the steepest slope and require the most effort to climb. A long ramp, with a gentle slope, is much easier to climb, but the distance you have to travel is much greater than when you use a ladder.

Fig. 1



Ladder

Stairs

Ramp



Lesson 5: Ramps

- Ask the children to talk about and compare their experiences of walking up steep hills, over gentle slopes, and along flat surfaces.
- Explain how ramps, stairs and ladders are all examples of a simple machine called an 'inclined plane'.

Let's Investigate - Ramps!

Working in Groups of 2-3

- Explain to the children that they will investigate how ramps (inclined planes) make it easier for people to move heavy loads from one height to another. In this lesson they will provide scientific data to a group of ancient Egyptian engineers who have to implement the design for the Pharaoh's pyramid. Everyone agrees that using a ramp is the best method to move the heavy blocks for the pyramid, but the engineers cannot agree on using a steep slope or a gentle slope to get the work done in time. One group thinks a shorter, steeper slope is best because the blocks only have to be moved a short distance, while another group wants a longer, gentler slope because the heavy building blocks will be easier to move using fewer people. Which way is best?
- The children's task is to provide the information that will help determine which type of ramp to use. They have two K'NEX ramps to use in their tests: one is steep and one is long. A 400 gram weight, or other heavy object, represents one of the stone blocks.
- Ask each group to build their K'NEX ramps, (Pages 9, 10 and 11 of the Building Instructions), but before starting their tests the children must first decide:
 - * How they will carry out a 'fair test' to determine which type of ramp should be used.
 - * What they will need to measure and how they will record their results?
 - * How they will measure the forces used to pull their 'loads' up the slope.
 - * How they will determine that using a ramp makes it easier to move a load through a vertical height.

Teacher's Notes

Simple machines are exactly what their name implies - simple 'tools' that make it easier for us to make something move. Simple machines cannot reduce the **amount** of work that needs to be done, but they enable us to change the **way** in which the work is done. For example, walking directly up a steep hill offers the shortest route but usually requires a large amount of effort. Taking a less direct, less steep route, however, requires less effort and will still get you to the top of the hill, albeit by a longer route. Inclined planes make it easier to move a heavy load through a **vertical distance**. Levers and pulleys are examples of other simple machines that will also undertake this task.

See: **A Quick Guide to Inclined Planes** for additional information.

- * For example: both ramps must be built to the same height.
- * The vertical height of the ramp, the length of the ramp and the force needed to pull the ramp up the slope.
- * The children could use a heavy-duty elastic band or a 10N Force meter to pull their loads up the ramp.
- * The children should measure the force needed to lift the load vertically to a height that is level with the top of the ramp.



* **How many measurements they will need to take?**

Building Tips

1: To complete Step 7 for the Long Ramp, slide the first section of the ramp over the yellow Connectors. Then slip the white joining plate (technical term = biscuit) into the end of the first section of the ramp. Finally, slide the second section of ramp over the yellow Connectors and the joining plate until the gap between the plates is closed.

2: Make sure the children construct both versions of the model so that the bottom end of the black plastic ramp touches the desktop. The models are designed to move an object through the same vertical distance and to ensure this happens, correct positioning of the black plastic ramp on the support structure is critical.

- Ask each group to discuss their observations and results. With the help of labelled diagrams and the use of correct vocabulary and terminology, they should describe and explain their findings.
- They should include their recommendations to the engineers as to the best type of ramp. Their recommendation should make use of the word 'because...'

- * **One measurement is not enough. The children should be encouraged to think about being able to reproduce their results. At least three readings should be taken on each test.**

Measuring forces: A force meter can be used to give measurements in Newtons. If force meters are not available then heavy-duty elastic bands could be used. The amount the elastic band stretches when the load is pulled up the ramp could give a non-standard measurement of the force required to move it.

The weight of the load may have to be reduced if heavy-duty elastic bands are not available. A risk assessment on using elastic bands with specific age groups should be made first. Please review the **safety recommendations** provided at the beginning of this Teacher's Guide.

Measuring height and length:

The children should be encouraged to observe that the vertical height moved by the loads in all three cases is the same, but the distances moved along the length of the ramps are different. Protractors also could be used to measure the slope angles.

They should also note that the least force (effort) is required to move the load up the gentle slope but the load moves the greatest distance. The vertical lift moves the shortest distance, but requires the greatest effort. In both cases the job to be done is the same.

The use of the ramp reduces the effort needed to move the load but that effort must be exerted over a longer distance. The steeper the ramp becomes, the greater the effort needed to move the load, but the shorter the distance involved.



Lesson 5: Ramps

Extension Activity 1 - The effects of friction

Whole class

- * Ask the children to describe the surface of the K'NEX Ramp and explain how this surface affects the movement of an object over it.
- Discuss how friction might affect the ability of workers to pull the heavy stones up the ramp.
- Would more or less effort be needed to pull the stones up the ramp if the surface was not perfectly smooth?
- How might they overcome the effects of friction?

Extension Activity 2 - Investigating friction

Working in Groups of 2-3

- Ask the children to repeat their investigation in order to find out how friction affects movement on an inclined plane. They could modify their ramps in the following ways:
 - Cover the ramp surface with coarse cloth or similar material.
 - Use a wheeled trolley/toy to move the load.
 - Use liquid soap as a lubricant (to simulate wet mud and/or oil).

Plenary

Ask the children to discuss and explain their observations and their recommendations to the pyramid-building engineers.

- * The ramp has a smooth plastic slope. This makes it easier to pull an object up the slope.

Teacher's Notes

Liquid soap is a good lubricant to use with plastic as it washes off easily. Avoid using near electrical components.

The coarse cloth creates a rough surface that increases the amount of friction between the surface of the load and the surface of the ramp. More force, or effort, is needed to move the load when the amount of friction is increased.

The trolley uses freely rotating wheels to reduce the amount of friction, as does the use of a lubricant. Less effort will be needed to move the load up the ramp.



Lesson 6: The Splitting Wedge



Time: 1.5 hours

Learning Objectives - Children should learn:

- to investigate and disassemble products in order to learn how they work
- about simple machines that make it easier to do things
- to relate science to the ways familiar machines work
- to communicate information about products and mechanisms through labelled drawings



Possible Teaching and Learning Activities

Introduction

Whole Class

- Review the previous lesson in which the children:
 - (i) discussed how less effort is needed to stroll up a gentle slope than to climb up a steep one, and
 - (ii) discovered how ramps (inclined planes) make it easier to lift a heavy load through a vertical distance by reducing the effort needed. The load, however, must be moved over a greater distance.

Whether the load has to be lifted vertically or pulled or pushed up a long ramp (inclined plane) to a given height, the job to be done in both cases is exactly the same. The only difference is in the way it is done.

- Explain that, in this lesson, the children will investigate how 'inclined planes' are found in many commonly used tools that are used to cut or split objects.
- Ask the children how easy, or difficult, it may be to (i) pull apart and (ii) tear apart a piece of paper using only their hands. One or two children could be asked to try this for themselves.



Vocabulary

wedge, inclined plane, force, effort, sideways, distance, force, increased, because

Resources

Each group of 2-3 children will need:

- 1 K'NEX Understanding Mechanisms: Wheels and Axles and Inclined Planes kit with Building Instructions booklet
- A4 Paper
- Scissors
- Felt-tipped pen
- Adhesive tape or dot stickers
- 4 large books (optional)

You will need:

- A collection of tools that incorporate wedges into their design. For example: knife, doorstep, hand axe, chisel and scissors.
- Apple/piece of cheese/piece of wood
- Magnifying glass

Useful Internet Web Sites

www.coe.uh.edu/archive/
The University of Houston archive of lessons. Search >Collections >Science > Simple Machines >Wedge.

For Reference

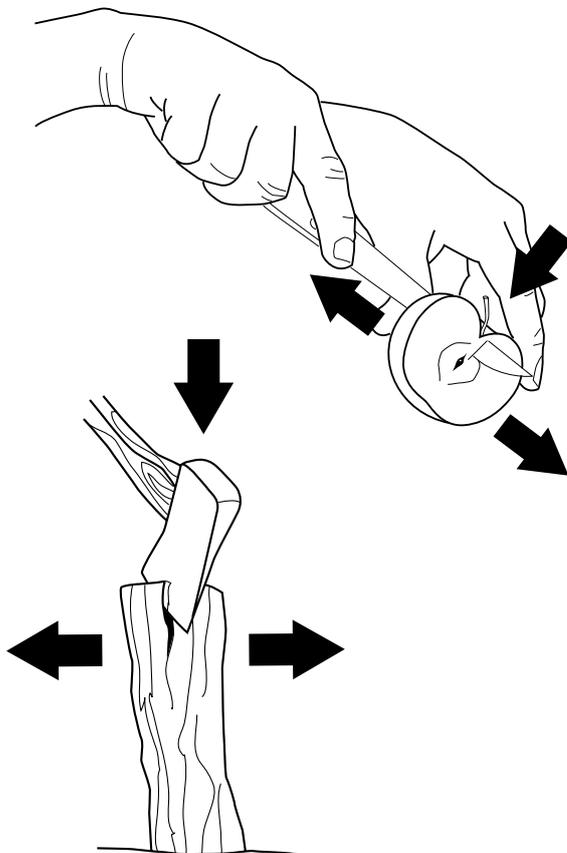
Macaulay, David. 'The Way Things Work.' Houghton Mifflin Company. 1988. Either the book or CD ROM is an excellent source of information.



Lesson 6: The Splitting Wedge

- Demonstrate how using scissors not only makes cutting paper very simple – the edges of the scissors are sharp - but also allows them to cut paper accurately in lines or curves.

- Talk about how other cutting tools work in similar ways.
- You may want to personally demonstrate how a knife cuts through an apple or a piece of cheese, or how a hand-axe can be used to split a thin piece of wood. Use caution regarding splinters that may be caused by the splitting of the wood. Ask the children to carefully observe what happens.



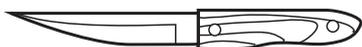
Teacher's Notes

They will find it very difficult to pull apart the sheet of paper because paper is strong when under tension, or stretching forces, but it is easy to tear. Tearing, however, produces very ragged edges.

The cutting edges of the scissor blades resemble two opposing knife blades moving across each other. As the blades slice down and up through the paper, the separated pieces move sideways. Use the magnifying glass to show the children the wedge shaped blade edges.

As the axe or knife moves downwards, the object splits and the separated parts move sideways away from the blade (wedge).

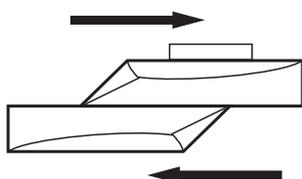
- Explain to the class how these tools are also examples of inclined planes.
- Draw the profiles of the different tools on the board and compare their shapes to the inclined plane investigated previously. For example:



Knife blade.



Axe head: Two inclined planes back-to-back.



Scissors: Two inclined planes moving in opposite directions across each other.

Optional Activity

- Ask the children to find examples of machines that use inclined planes or wedges in their mechanisms. They should describe and explain how they work, using labelled drawings and text. For example: zip fasteners, ploughs and locking systems. You may want to suggest that they investigate how a wedge is used to 'lock' the wooden handle into the metal head of a hammer or axe.

Let's Investigate – How Wedges Work!

Working in Groups of 2-3

- Ask the children to build the K'NEX Splitting Wedge model (Pages 12-13 of the Building Instructions).
- Ask them to plan how they will make the two components of the K'NEX model when given only 10 minutes to complete the task.
- To help the children's observations, ask them to mark the two halves of their K'NEX 'log' and the tip of their wedge with dot stickers or adhesive tape.

Teacher's Notes

A wedge used in a cutting tool acts like a moving inclined plane. Instead of the object being moved up the inclined plane, the plane itself makes the object move.

The same principle applies: the wedge moves a greater distance into the object than the sideways movement of the cut side. The sideways cutting forces, therefore, are greatly increased.



Lesson 6: The Splitting Wedge

- Ask the children to observe and record what happens when the wedge is pushed into the K'NEX 'log'.
 - In which direction does (i) the point of the wedge and (ii) the sides of the 'log' move?
 - Which moves the greater distance, the point of the wedge or the sides of the 'log'?
 - (Optional) Why is their K'NEX wedge an example of an 'inclined plane'? You may want to suggest that they turn their model on its side and compare the wedge, as it moves into the 'log', with the ramp they investigated in the previous lesson.

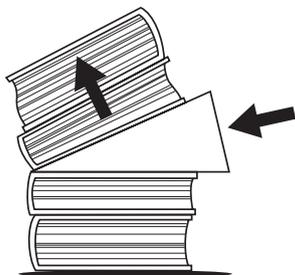
Whole Class

- Discuss the children's observations and findings.
- Ask the children to record their observations and results. Making use of the correct vocabulary, they should write notes to explain how the mechanism works. They should also include annotated diagrams, with arrows to show the direction of movement of the different parts.

Alternative Investigation

Working in Groups of 2-3

- Ask each group to stack four heavy books on top of each other. Using just the fingertips of one hand, they should take turns lifting up two of the books. Ask the children to notice how this feels.
- They should then repeat the activity using the K'NEX splitting wedge to lift the same two books. As they tap in the wedge they should notice in which direction the books move. They should also compare how easy, or difficult, it was to lift the books with the wedge compared to their fingertips.
- Ask them to repeat the experiment once more, this time lifting all four books. What do they notice?
- The children should record their observations and include a labelled diagram.



Plenary

Ask children to discuss and explain their observations.

Teacher's Notes

The children should note:

- The sides of the 'log' move at right angles to the movement of the wedge.
- The point of the wedge moves a greater distance than either side of the split 'log'. The more they push down, the more the log separates. The sideways forces generated from the action of the wedge can be very large.
- The K'NEX wedge model is really two inclined planes arranged back-to-back. This is similar to an axe head.

To promote the wider use and application of ICT skills and practices, the children's models and work might be recorded using a digital camera.

The children should notice that it is more difficult to lift the books using their fingertips than it is using the wedge, especially when they try to lift all four books. As the wedge is inserted, the books move at right angles to the movement of the wedge.

Brain-teaser

Can wooden wedges be used to split solid rock?

Yes, surprisingly! From very early times, quarry workers hammered dry wooden wedges into cracks in rock and then soaked the wedges with water. The wedges expanded, generating enormous sideways forces that were large enough to split the rocks.

Lesson 7: The Hand Drill



Time: 1 hour

Learning Objectives - Children should learn:

- to investigate and disassemble products in order to learn how they work
- about simple machines that make it easier to do things
- to relate science to the ways familiar machines work
- to communicate information about products and mechanisms through labelled drawings



Vocabulary

inclined plane, spiral, vertical, linear motion, rotate, groove, slope, diagonal, right angled triangle, screw

Resources

Each group of 2-3 children will need:

- 1 K'NEX Understanding Mechanisms: Wheels and Axles and Inclined Planes kit with Building Instructions booklet
- A5 Paper
- Pencil (full length) or an equivalent length of thin dowelling
- Felt-tipped pens
- Scissors
- A range of tools and components that have screw mechanisms
- Hand drill and drill bits
- Small coffee tin or similar container (approximately 9 cm diameter)
- 6 table tennis balls or small polystyrene or similar balls
- Rulers

For Reference

Macaulay, David. 'The Way Things Work.' Houghton Mifflin Company. 1988. Either the book or CD ROM is an excellent source of information.

Possible Teaching and Learning Activities

Introduction

Whole Class

- * Talk about the children's experiences using a spiral staircase or spiral water slide. Would it take them longer to go into the water using the slide or jumping off a diving board? Why?

- * They have to travel a much longer distance using the slide than if they jumped straight down from the diving board.

Lesson 7: The Hand Drill

- Ask why they think firemen slide down a pole to reach their fire engines in emergencies and not a spiral staircase or spiral slide?

Teacher's Notes

Going vertically down the pole is the fastest route. A spiral staircase would take too long because it is a longer distance than the vertical slide down the pole.

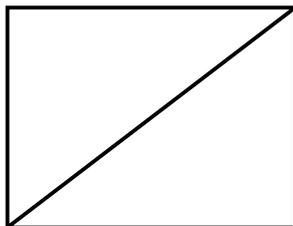
Explain to the class that using a spiral allows a gentler descent and an easier way to go up when compared to going straight up or down. The vertical distance they travel is the same in both cases; the only difference is the route they take.

Remind the children that they explored this concept when they investigated the ramp. They discovered it requires less effort to go up a gentle slope than a very steep one although, to reach the same height, the gentler slope will involve travelling over a longer distance.

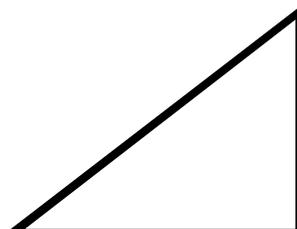
Each pair will need an A5 sheet of paper, felt-tipped pen, ruler, scissors, pencil or thin dowelling.

Let's Investigate – Changing a slope into a spiral. Working in pairs (or whole class demonstration)

- Ask the children to complete the following:
 1. Fold an A5 sheet of paper across a long diagonal from corner to corner; then cut the paper along the fold line to make 2 right angle triangles.



2. Use a felt-tipped pen to draw a thick line along the long diagonal edge they have just cut.





3. Measure and record the length of the marked edge.

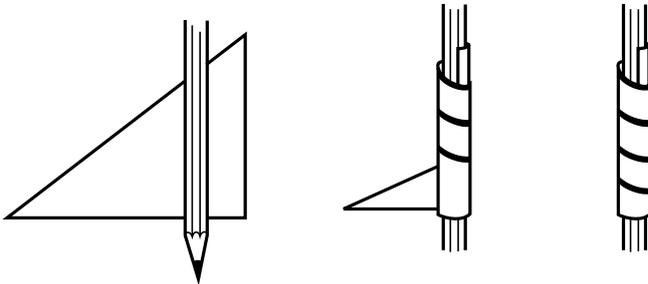
* **Ask what the shape of the right angle triangle resembles.**

4. Place the paper on the desktop so that the marked edge is face down.

5. Place the pencil or dowelling along the short vertical edge and roll the paper around it.

6. Measure the length of the pencil/dowelling covered by paper.

7. Compare the length of the pencil/dowelling covered by paper with the length of the marked edge of the paper.



* **Ask the children to describe the shape made by the marked edge.**

* **What other familiar objects do they know that have this shape and what are they used for?**

Whole class

- Demonstrate how to safely use the type of hand drill the children may use in Design and Technology lessons.
- Ask if it would be easy to push a nail or screw or drill bit into a piece of wood by hand? Why or why not?
- Ask the children to observe how the hand drill works.

* **What type(s) of movement does the handle make?**

* **What type(s) of movement does the drill bit make?**

* **How are the wood shavings removed from the hole by the drill?**

* **An inclined plane.**

* **A spiral.**

Teacher's Note's:

Make a list on the board of the objects and their function. For example: Screws, nuts and bolts, hand drill bits, cork screws, screw tops for bottles and jars, water tap, bench vice.

* **Circular or rotary motion.**

* **The drill bit rotates and cuts vertically down through the wood. The movement through the wood is linear motion.**

* **They travel up the spiral groove in the drill.**

Lesson 7: The Hand Drill

Teacher's Note's:

If resources permit, allow the children to investigate, first hand, the structure of a real drill bit, especially noting the spiral grooves that run along its length.

Please refer to the Safety Guidelines in this guide to ensure adequate safety measures are taken.

A hand drill usually has a small gear wheel turning a larger gear wheel that turns the drill bit. The gear arrangement of a small gear wheel turning a large gear wheel makes it easier to turn the drill bit in the wood.

Working in Groups of 2-3

- Explain how the children will make a K'NEX model of a drill bit to investigate how it works.
- Before starting to build their model, ask each group to plan how they will make the two components of the K'NEX model if they are given only 10 minutes to complete the task.
- Allow each group time to investigate how the design of their hand drill might work.

* **What is the shape made by the yellow Flexi-rod edges?**

* **Which is longer, the yellow Flexi-rod edge or the drill length?**

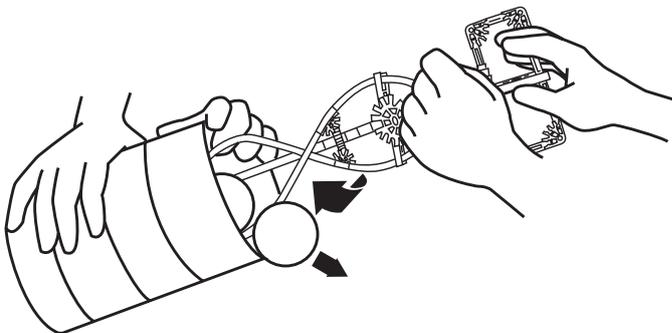
- Each group should have an opportunity to try their K'NEX hand drill mechanism by 'drilling' into a coffee tin filled with polystyrene or table tennis balls.

* **What happens to the balls?**

* **Double spiral.**

* **Flexi-rod edges.**

* **Some balls will be pushed up and out of the tin.**



The drill will work better if the coffee tin is turned over to one side. When 'drilling' into the can, the balls are pushed up and out of the can along the drill bit's spiral edge. The same thing happens when a drill bit makes a hole in wood. The waste materials cut by the chisel-like tip are channelled away along the screw shaped grooves.



Ask the children to record their observations and results. Making use of the correct vocabulary, they should write notes to explain how the mechanism works. They should also include labelled diagrams, with arrows to show the direction of movement of the different parts.



Source: American Museum of Natural History

Extension Activity (Optional)

- Using the school library and Internet the children should investigate the Archimedes' Screw to learn about its design and how it worked. Their research should discover how it was used 2000 years ago and how it is used to day.
- Working in small groups: Design and make an Archimedes' Screw, using the K'NEX kit, that can raise table tennis or small polystyrene balls from a coffee tin.

Extension Activity 2 – Design and Make Class Challenge

Working in small groups:

- Ask the children to use their knowledge of how objects move up and down inclined planes, to design and make a system for a table tennis ball to take the longest time to descend from a height of 30cm.

The groups can use K'NEX kits and any other materials made available in their classroom.

Plenary

Choose some models to share with the class and ask the children to describe:

- The reasons behind their design.
“We did this because...”
- Why their design works well.
- What parts of their design they are pleased with.
- What tests they carried out to evaluate their design against the design brief?

The path of the spiral is upwards, just like any inclined plane. The only difference is that this inclined plane spirals around the shaft of the drill. The same inclined plane rules apply. While the drill bit only moves a short distance into the wood, the drill bit, itself, has rotated through a much greater distance. This requires less effort than trying to push the drill bit directly into the wood.

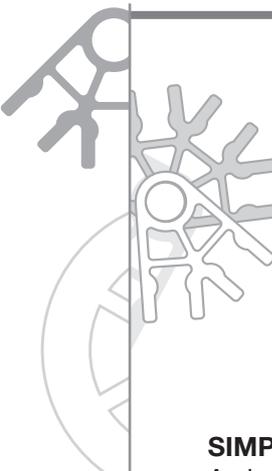
The Archimedes' Screw consists of a screw inside a cylinder with an opening at each end and a handle to turn the screw. When one end of the screw is lowered into a body of water and the handle at the other end is turned, water enters the screw at the lower end and is moved up the spiral, exiting at the top end. Today, Archimedes' Screws continue to be used for irrigation purposes when water must be raised to a higher level, but they can also be found, for example, in machines that transfer grain and as devices for removing rubble from excavation sites.

Augers are a form of Archimedes' screw. The Combine Harvester makes use of several Archimedes' type screw mechanisms.

Useful Internet Site:

www.mcs.drexel.edu/~corres/Archimedes/contents.html

Key Technical Terms and Scientific Definitions



*This list of key terms is intended as background information. While we recognize that some of these terms are not fundamental to National Curriculum requirements for Key Stage 2 Design and Technology and Science, we have nevertheless included them here to help you better understand some of the concepts investigated in the **K'NEX Understanding Mechanisms** kits.*

SIMPLE MACHINE

A simple tool used to make jobs easier to do. For example, a lever allows you to apply a small force to move a much larger load. Try pulling a nail out of a piece of wood without a claw hammer. A claw hammer uses the lever principle in its design. Other examples of simple machines are wheels and axles, pulleys, inclined planes or ramps, wedges, and screws.

Simple machines can be used to increase forces or change the direction of a force needed to make an object move. They are simple because they transfer energy in a single movement. Simple machines make it easier for you to do jobs by changing the **way** in which jobs can be done; they cannot change the job to be done. For example, you can load a heavy object onto the back of a lorry by lifting it the short vertical distance – a process that will require a lot of effort. Alternatively, you can take the longer but easier route up a ramp with the object. Either way, the job is done.

In science, when an object is moved by a force **work** is said to have been done. Simple machines make it easier for you to do work. Some simple machines allow a small force to move a large load and are called **force amplifiers**. For example: crowbars and wheelbarrows. Other simple machines can be used to convert small, slow movements into large, faster movements. Such machines are **distance or speed amplifiers**. A fishing rod used to cast a hook, or a mediaeval throwing machine, such as a trebuchet, are examples of this application.

COMPOUND MACHINES

These have two or more simple machines working together in their mechanism. For example, two 1st Class levers make up a pair of scissors, or pliers, while a complex car engine may be made from several hundred mechanisms.

WORK

Work is a scientific concept and is only done when a force moves an object in the same direction as the applied force.

If you push against an object and it does not move then, from a scientific point of view, you will not have done any work. For example, no matter how hard you push in an attempt to move a car while its brakes are on, you will have not done any work if it has not moved. Once, however, the brakes have been released and the car starts to move, then you will be doing work. The amount of work you do depends on the magnitude of the force you apply and the distance you move the object.

Work = Force x Distance moved by the object in the direction of the force

$$\text{or}$$

$$\mathbf{W = F \times d}$$

If the force is measured in **newtons** (symbol **N**) and the distance is in **metres** (**m**) then the **work done** (**W**) is measured in **newton metres** (**Nm**).

The SI unit of work is the **joule** (**J**) and **1 joule = 1 newton metre**.

FORCE

A force is a push or a pull which, when applied to an object, can make it change shape, move faster or slower, or change direction. You cannot see forces but you can feel or see their effects.

A force has both size and direction. The size of a force is measured in **newtons** (**N**) and can be measured using spring balances called **force meters** or **Newton meters**.

EFFORT

The force you apply to move one part of a simple machine, i.e. the **input force** that is applied to a simple machine, or mechanism, to make it do work. With a wheel and axle simple machine, the effort force can be applied to either the wheel, or the axle, in order to make the other part move. Think of a waterwheel being turned by a millstream or a car axle driving the road wheels. The function of a simple machine, or mechanism, is to transfer the force both to the location and in the direction in which it is needed to move the **load**.

LOAD

The **weight** of an object to be moved or the **resistance** that must be overcome before an object can be moved.

The resistance can be the **frictional forces** in a mechanism itself or simply the **friction** between two surfaces.

RESISTANCE

The force that works against the effort. It could be either the weight of the object to be moved and/or frictional forces.

FRICTION

The force that occurs when two surfaces rub against each other. Friction tends to slow things down, which means it can be both beneficial and unhelpful. For example: friction is beneficial in the case of brakes applied to the wheels of cars and bicycles to slow them down, but friction between surfaces can also cause wear - tyres wear out. Rough surfaces increase friction, while smooth surfaces reduce it.

Friction also generates heat. You can feel this when you rub your hands together quickly.

Key Technical Terms and Scientific Definitions

MECHANICAL ADVANTAGE

Most machines are designed to make jobs easier to do. For example, a wheelbarrow that allows you to move a heavy load of soil or a winch used to lift a heavy object. When a machine enables you to use a small effort to move a large load, that machine has given you a “mechanical advantage” you would not otherwise have had. How large or small a mechanical advantage a machine provides can be measured by comparing the load you can move with the effort you used to move it.

The calculation used is:

$$\text{Mechanical Advantage (MA)} = \frac{\text{Load}}{\text{Effort}}$$

The mathematical calculation indicates how many times the machine multiplies the effort force.

For example, if a machine allowed you to move a load of 300N using a 100N effort force, the mechanical advantage of the machine will be 3:1 or simply 3.

If the value of the MA is greater than 1 then your machine allows you to move a large load using an effort force less than that of the load. Does this mean you can get something for nothing? Can you get more from less? Unfortunately this is not the case. While a high MA value means you can use less effort force than that of the load to be moved, the distance moved by the effort will be much greater than that moved by the load. This is the trade-off.

Remember, simple machines and mechanisms can make it easier to do a job by changing the way in which the job is done; they do not change the actual job to be done. The work needed to be done will always remain the same, so that to move a load, you can use a large effort applied over a short distance, or a small effort applied over a longer distance. It all balances out in the end.

MECHANISMS

Although designed and made to do different jobs and make jobs easier to do, all mechanisms share some common features.

- They are made from simple machines, either used singly or in combination.
- They involve some form of motion.
- They need an input force to make them work.
- They produce an output force and motion of some kind.

TYPES OF MOTION

4 basic forms of motion are used in mechanisms:



- **Rotary:** This can be seen in the movement of car, bicycle and gear wheels and in Ferris wheels or carousels as they go round and round on an axis. It is the most commonly occurring type of motion in a mechanism.



- **Oscillating:** This is an alternating, or swinging to and fro, type of motion. It can be observed in car windscreen wipers, children's swings or in pendulums as they move backwards and forwards in an arc.



- **Linear:** This is motion occurring in a straight line, in one direction. Examples include the linear movement of a paper trimmer, a sliding lock, or a conveyor belt.



- **Reciprocating:** This involves an alternate backward and forward motion, in a straight line, as in the movement of a sewing machine needle or the pistons of a car engine.

One form of motion (**input**) can be converted into another (**output**) through the use of **a mechanism (process)**.

TYPES OF SIMPLE MACHINES

- **Lever:** A rigid beam, bar or rod that turns, or rotates, about a fixed point called the fulcrum. For example: a child's seesaw.
- **Wheel and axle:** A round disk (wheel) with a rod (axle) rigidly connected through the centre of the wheel so that they both turn together. A wheel can be used to turn an axle or an axle can be used to turn a wheel. For example: a winch raising a bucket from a well. The wheel can be a solid, circular disk, such as a car wheel, but it can also be the circular path made by a handle that turns, such as a lever rotating around a fixed point.
- **Gear:** This is not a simple machine but it could be thought of as a wheel with teeth around its outer rim. Gears are used to transfer motion and force from one location to another, change the direction of rotational motion and amplify the force applied to do a job.

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- **Pulley:** A wheel with a groove in its outer rim that spins freely on an axle. A rope, cable, or chain runs in the wheel's groove and may be attached to a load. As the wheel turns, the rope moves in either direction so that a pull down on one side will raise an object on the opposite side of the wheel.

- **Fixed Pulley:** A pulley attached to a solid surface; it does not move when the rope is pulled, other than to turn in place. Fixed pulleys change the direction of an applied force.

- **Movable Pulleys:** A pulley attached directly to the load being lifted; it moves when the rope is pulled.

- **Combination Pulleys:** A series of fixed and movable pulleys used together to gain the advantages of both in doing the work.

- **Block and Tackle:** A specific combination of fixed and movable pulleys used to lift very heavy objects; the block is the frame holding the pulleys; the tackle is the rope or cable.

- **Inclined Plane:** A flat surface with one end higher than the other. The most recognisable form of an inclined plane is a **ramp**. Ramps make it easier to move from one height to another.

- **Screw:** A shaft (body) that has an inclined plane spiralling around it. The inclined plane forms ridges (threads) around the shaft to become another simple machine: the screw. It can be used to lift objects or fasten two things together.

- **Wedge:** A device made of two inclined planes arranged back-to-back. Instead of moving up the slope, wedges themselves move to push things apart. Wedges are inclined planes that move pointed-end first and are used in many cutting tools such as axes, knives and chisels.