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Acknowledgements

The Science of Circus

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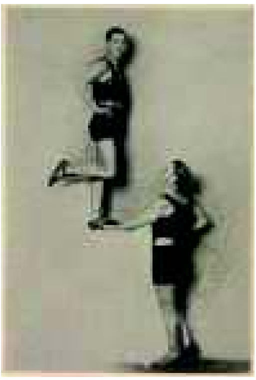
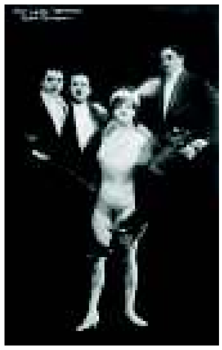
- **Pictures**

			
Shoulderstand; the C of G is directly through the flier's left leg.	This is a dynamic balance with a bowl of water balanced on the head.	Is this balanced?	How about this?
			
This balance requires strength and concentration	A chalk 'mushroom' etched by the wind in Egypt's White Desert.	The Mexican Hat in northern New Mexico.	Taking walking on point to extremes.
			
Where is the C of G in this balance?	How many balances are going on here?	Is the rider balancing the bike, or balancing *on* the bike or both?	No mean feat!
			
A precarious balance, but how high is he?	Off balance or not?	It's not just the difficulty of the balance, it's also the penalty for failure.	You just can't stop them showing off!

- **Curriculum Links**

Moments, Gravity, Mass, Weight, Centre of Gravity, Balanced Forces

- **Educational Objective**

To use pupils science knowledge of forces and apply it to an unusual situation.

- **Key learning**

Experimentation, measurement, observation, teamwork.

- **Materials Required**

1m long ruler or tape measure.
Weight Scales in Newtons or mass scales in Kg (x10 to convert to Newtons)
A second 1m ruler, a straightedge or length of heavy rope around 1m long
Small stickers to place on hip bone as the marker for measurement
Projection of slides or video

- ***Teacher Aware (Practicalities)***

There are risks in this experiment and precautions must be taken to make the experiment safe. The main risk occurs as the two students lean backwards if they let their grip slip or let go then there is the danger of a backwards fall for one or both students and a potential collision with objects in the room during the fall.

The Instructions for the Teacher must be clear and judgements need to be made on the risks associated with the behaviour of individual pupils. Risks can be reduced by performing the experiment in a hall with space between groups to avoid collisions.

Discussion Points

How accurate are the results?
Do they show a trend?
Is it important to have a high degree of accuracy?
How might we improve the accuracy?
Would accuracy be improved with acrobats of widely different weights or of about the same weight?
Does the height of the acrobat make any difference?

Real world Examples

The pictures that accompany this module show a number of things in balances of various kinds. Using what you know about balancing forces and stable and unstable equilibrium, examine each of the photos, describe their state of balance and mark a line through their centre of gravity. Are all these photos genuine, or have camera tricks been used?

N.B. The tower of Pisa is a special case in that it would be falling over if it weren't, in effect, secured to an enormous lump of concrete buried in the ground.

Science Experiment

This experiment calculates the force contributed by each acrobat.

1. Measure the weight of each acrobat.
2. The acrobats lean out in the balance as practiced earlier.
3. A fifth pupil holds the straightedge, a rope or a stout cord vertically between the acrobats – with one end touching the floor right where the acrobats' toes meet.
4. A sixth pupil measures the two (different) HORIZONTAL distances from each acrobat's hip to the Centre of Gravity line. Be sure that the acrobats do not twist their hips; the acrobats *must* be facing each other.

Calculations

The Clockwise Moment is calculated by multiplying the weight of the person on the RIGHT by the HORIZONTAL distance their hip to the centre of gravity line.

The Anti-clockwise Moment is calculated by multiplying the weight of the person on the LEFT by the HORIZONTAL distance from their hip to the centre of gravity line.

Acrobat	Weight (Newtons)	Distance (cm)	Moment = Weight x Distance (Ncm)
A			
B			

Prediction

Since the parties are in balance these moments should be equal and opposite.

Discussion of Results

This is not a precise science because of the following factors:

i. The participants may not be holding their bodies completely straight.
ii. If their hips are twisted then inaccuracies can creep into the measuring.
iii. One acrobat may have most of their weight on their heels, the other on their toes. This will mean that the C of G may not, in reality, pass exactly between them.

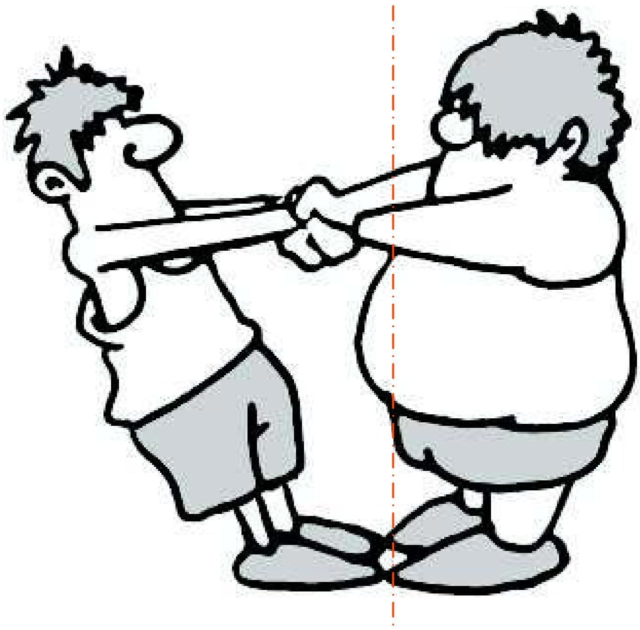


fig 5

Answer Resource:

If one acrobat is heavier than the other the lighter will have to lean further out to keep the bodies in balance. But since they are in balance the line of the Centre of Gravity must still pass through their feet – otherwise they would have already fallen over. However since the heavier acrobat is not leaning as far out as the lighter one the line of the Centre of Gravity will pass much closer to him (*fig 5*).

The acrobatic balance is in a state known as 'unstable equilibrium', they are balanced but if you were to push them they would fall over. Compare this with, say, a building which is in a state of 'stable equilibrium'. Not only is it in balance, but it will stay in balance until it's demolished.

Is standing-up a state of stable or unstable equilibrium?
Is walking a state of equilibrium or of controlled falling?

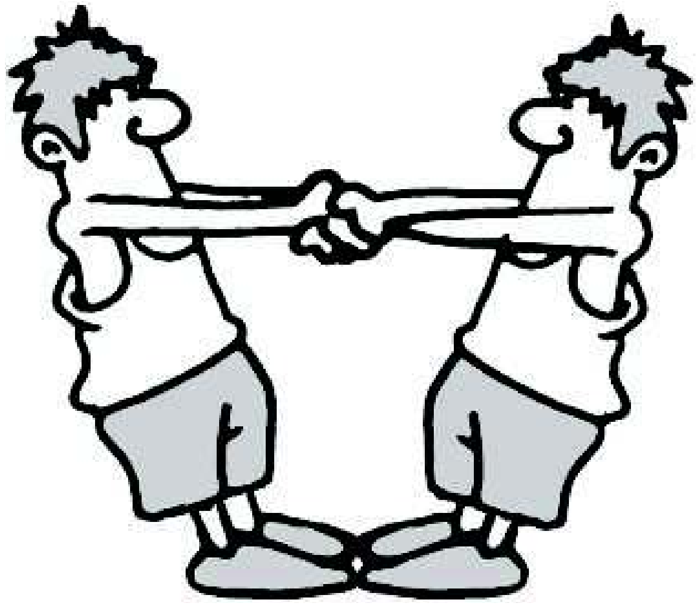


fig 3

Leaning backwards, arms straight

The two ***acrobats*** should then lean backwards and at the same time slowly extend their arms forwards toward each other. The acrobats must keep their body straight and feet still. The two bodies form a V shape, with the base of the V being their feet. In acrobatics this position is called a "counter-balance".

Question: Are the ***acrobats*** balanced?

Yes as they do not fall over. However they are only balanced 'as a unit', each individual acrobat – if the other was removed – would fall over.

Extension Questions:
How they are balanced?
Why do they not fall over?
How have the forces changed compared to when they were standing?

Question: Where is the line of the Centre of Gravity?

Answer Resource:

The acrobats are roughly the same mass and therefore weight. In order to remain in balance they must lean out roughly the same amount.

The line of the Centre of Gravity runs approximately through the clasped hands and touching toes (*fig 4*).

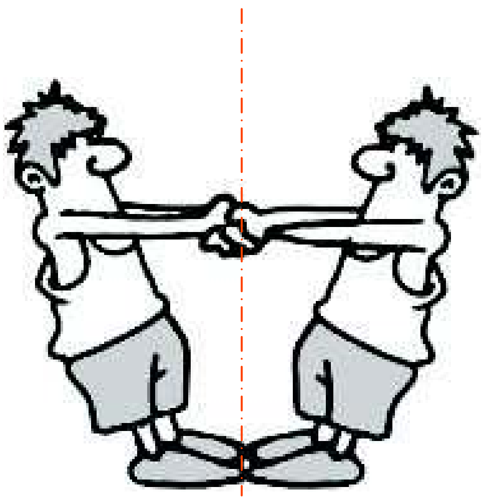


fig 4

Question: What happens if the acrobats are different masses? Where is the line of the Centre of Gravity now?

Forces at Play - Acrobatic Balancing

A demonstration of how circus performers use balancing forces to amaze their audiences.

- **Yr 10/11 Key stage 4**
- **Activity Description**

The experiment requires pupil participation, some controlled risk and teamwork.

Short Class Activity (2mins)
Pupils stand still and then balance on one leg. This leads to a short discussion on how gravity interacts with them. How does the centre of gravity change when pupils stand on one leg? The silhouettes below show how our weight distribution changes when we raise one leg .

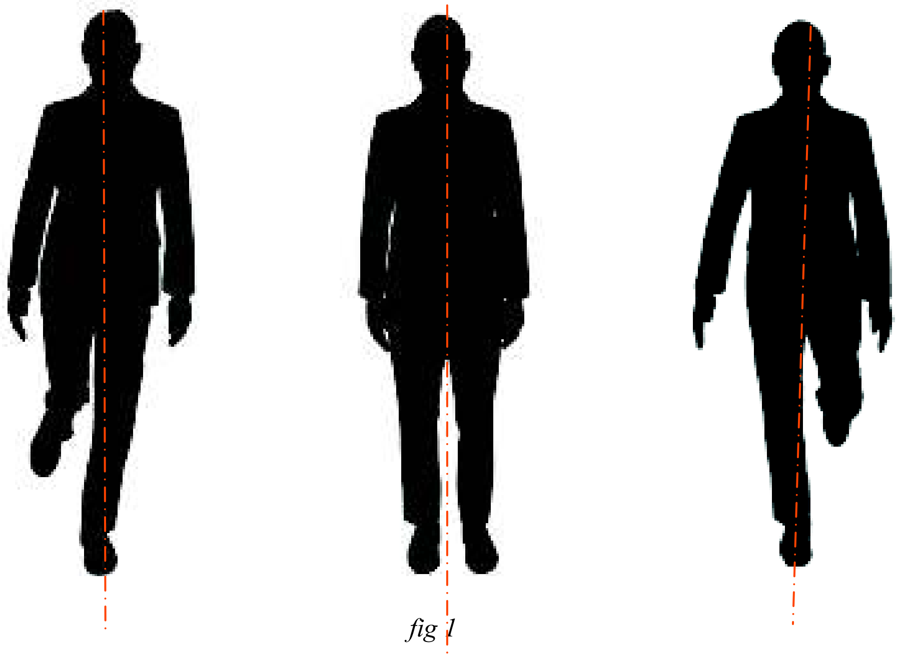


fig 1

Interactive Experiment

It is recommended that the interactive experiment is demonstrated by a group of four volunteers under teacher supervision before being attempted by the whole class.

Choose four pupils, two **acrobats** (who are roughly the same size) and two **safety crew**. The acrobats stand face to face with their toes touching. They should cross their arms and grip each other's wrists, (*fig 2*) and stand with their elbows bent and held tight to the sides of their body.

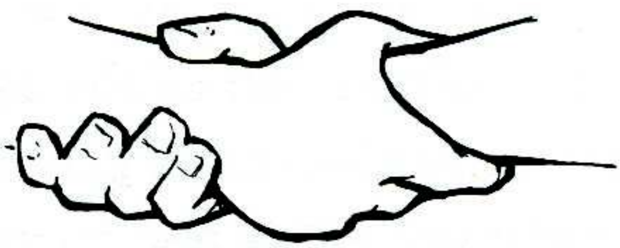
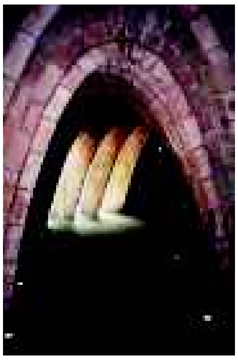
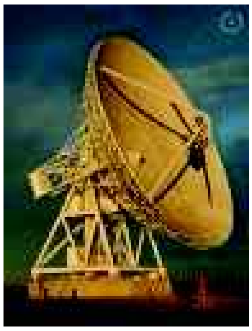
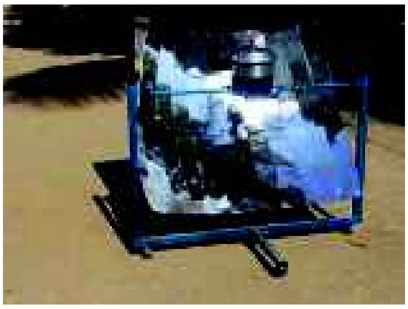


fig 2

Cross-arm grip

The other two pupils (***the safety crew***) stand one behind each of them. The safety crew's job is to make sure the acrobats don't fall over, over balance or bend the body (usually by sticking the bottom out or leaning over). They also monitor and control the experiment.

- **Pictures**

		
The St. Louis Arch	Parabolic arches at La Pedrera, Spain.	Ubiquitious golden parabolas.
		
Nature's own Golden Arches	Painting makes very little difference, it's the shape that's important, not the colour.	Expensive radio telescopes are probably best left unpainted.
		
This parabolic cooker is heating the pressure-cooker at its focus.	Nature's forces in all their beauty.	The vomit comet in action.

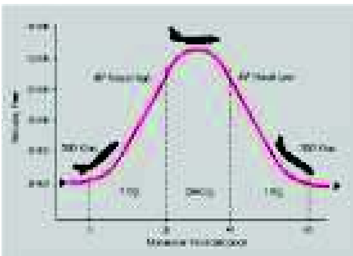



Diagram showing the flight path and periods of weightlesness.		

- **Extensions**

Try throwing the balls in a high, narrow path.
Try throwing a low, wide flight-path.
What angle of throw will give the widest flight-path?

If the natural curve for a thrown ball is always a parabola, why does the high narrow flight-path look completely different from the low wide flight-path?

The diagram below shows that a low wide flight-path is simply a small section of the same trajectory as a high narrow flight-path.

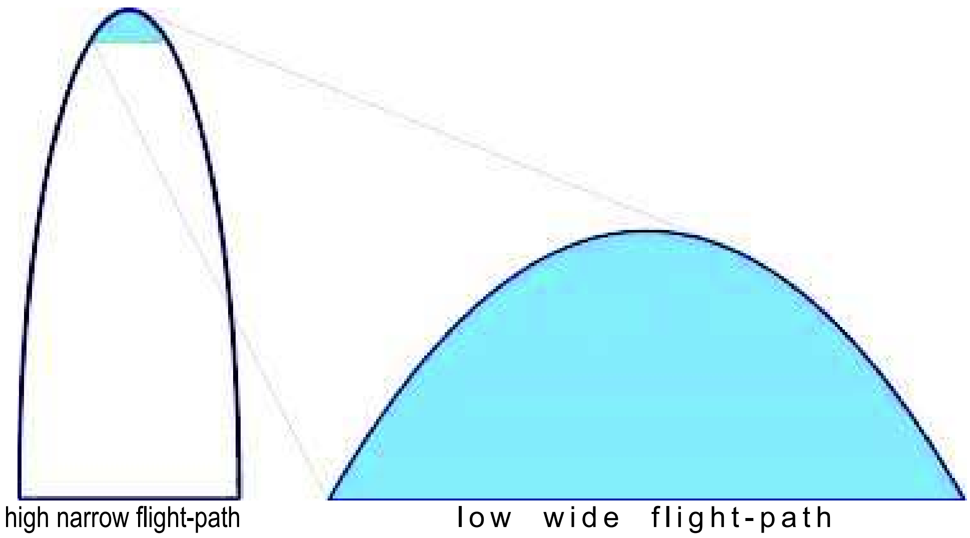


fig 4

- **Links to everyday life**

The parabola is a natural and very useful shape. It has the property of bringing incoming waves – electromagnetic or sound – to a focus.
A parabola is the shape of many everyday objects from car headlight reflectors to satellite dishes.

Microphones with parabolic reflectors are used by naturalists, spies and sound engineers to record distant or quiet sounds.

The latest hi-tech solar furnaces use parabolic mirrors to focus the sun's rays to generate the 3,500 °C required to make some of the newest materials such as carbon nanotubes.

A parabola is also the flight-path that the 'vomit-comet' aeroplanes take to create zero-gravity conditions for training astronauts.

- **Other Resources**

The Complete Juggler by Dave Finnigan, Jugglebug 1991 ISBN 0-9615521-0-7

The pictures that accompany this module not only show some valuable uses of parabolas but also that it is one of nature's naturally occurring and most beautiful shapes.

- **Curriculum Links**

Science 3.1a
3.1b
4c

- **Educational Objective**

The pupils will be able to describe how gravity affects thrown and falling objects.

- **Key learning**

Hand-eye co-ordination, concentration, focus, problem solving.

- **Materials Required**

3 x juggling balls
Projection of slides or video

- **Teacher Aware (Practicalities)**

The juggling balls are soft and harmless to all practical intents and puposes.

There are only two forces at work when juggling, the force the juggler imparts when they throw the ball, and the force of gravity. The force of gravity will always act directly downwards, whereas the juggler can throw the ball in whatever direction they please. The skill of juggling is learning exactly where to throw the ball and with what force.

Hints & Tips

Juggling is overwhelmingly about throwing and not about catching, despite how it may seem. If the throw is right then the ball should simply drop into your hand.

If you seem to be having a block with step 2, then forget about the catching but be sure to continue to throw *as if* you were going to catch them.

A lot can be learned by seeing where a ball lands when a catch is missed; it shows precisely how bad the throw was. If, as an experiment, the balls were deliberately not caught they should land on the floor within easy arm's reach, so that you could have caught them if you'd tried.

Stand relaxed, particularly in your shoulders.

Most of the action should be with your forearms, not your wrists.

'Scoop' the balls upwards, rather than 'flick' them

- **Discussion Points**

What shape is the flight-path of the thrown ball?
Is it easier to catch a ball thrown high or one thrown low?
Is there an optimum height for juggling?
Under what specific conditions might the ball's flight-path *not* be parabolic?

Consider the calculations your brain must be doing in an instant, in order to catch the ball without ever looking at your hand.

Gravity – juggling up to three balls

An exercise to explore the effects of gravity on the flight-path of a thrown object.

- **Year 8/9 Key Stage 3**

- **Activity Description**

This activity is one in which each pupil takes part individually. It can easily be broken down into three steps. The first step will take a few minutes, the second step could take up to 10 minutes and the third step may take some pupils hours to get working smoothly!

Step 1 Starting with only one ball, practice throwing it from hand to hand, the throw from the right hand should peak slightly to the left of centre; the ball thrown from the left hand should peak slightly to the right of centre. Each hand must throw the ball to the same height. (*fig 1*)

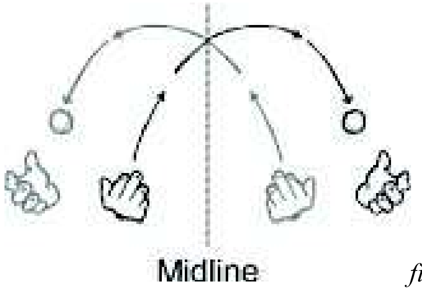


fig 1

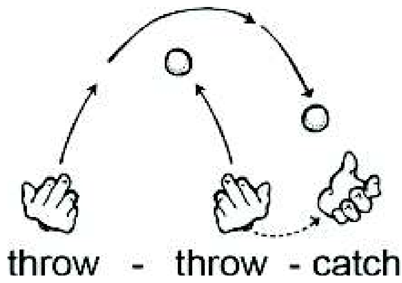


fig 2

Step 2 Moving on to two balls; hold one in each hand. Throw the ball from your dominant hand first and when it is at the peak of its travel, throw the second ball from the other hand, followed immediately by catching the first ball (*fig 2*). The first hand will then catch the second ball. The pattern is throw, throw, catch, catch, in an even, regular, four-count.

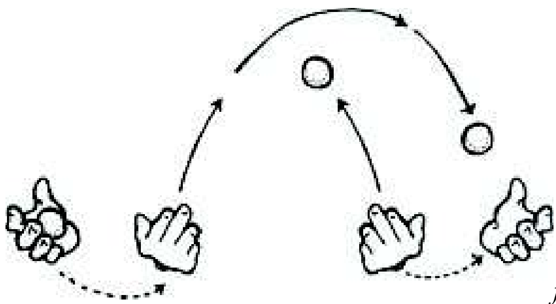


fig 3

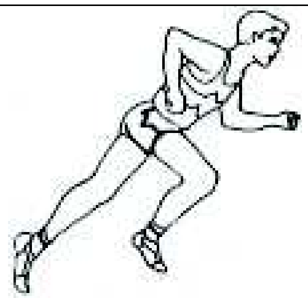
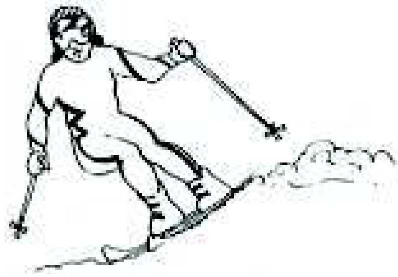
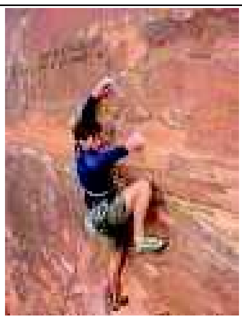
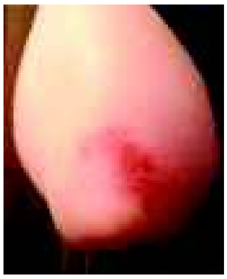
Step 3 With three balls; start by throwing one ball from the hand with two balls in it and when that ball reaches its peak throw the ball from the opposite hand. When that ball reaches its peak throw the second ball from the first hand (*fig 3*).

Don't forget to do the catching too! From then on it's simply a regular, even, left, right, left, right.

Don't think about it too hard, just do it. At any given time there will be one ball heading upwards, one ball heading downwards and one ball in a hand.

However many balls you juggle, the flight-path remains the same, with each ball peaking over the opposite shoulder to the hand that threw it.

- **Pictures**

		
A sprinter relies on high friction to get a good start.	A skier needs minimum friction for maximum speed, however that presents problems cornering.	Ice skates work by floating on a film of melt-water.
		
Rock climbers require maximum friction .	'Zero Friction' golf tees improve the energy-efficiency of the shot.	In-line skates: maximum friction laterally, minimum friction longitudinally.
		
Reducing friction is the primary function of these bearings.	Converting friction into heat is the primary purpose of these brake pads.	Friction-burns can be very painful.
		
This conveyor-belt motor is a friction-fit into a roller element.	This 'Grace' banknote counter relies on friction and is fast and accurate.	NASA using a 'friction welder' to give strong, accurate welds with no flames or sparks.

Hints & Tips
Always roll the diabolo *from* your dominant side *towards* you subordinate side. Pick the diabolo off the floor as it comes level with your feet and immediately begin 'tapping', or 'whipping', with your dominant hand.

The diabolo must remain level, not tipping away from you, not tipping towards you. The tipping can be controlled by moving your dominant hand-stick towards you and away from you; if the diabolo tips towards you, 'push' it away with your hand-stick; if it tips away from you 'pull' it back and vice-versa.

You should always be looking directly along the axle of the diabolo, it must not be at an angle across the string. If the diabolo 'twists' on the string then you must turn to face it.

It is possible to practice the throw without the diabolo spinning. Place it in the centre of the string and hold it a few inches off the ground. Sharply pull the sticks apart, straightening the string and flicking the diabolo upwards. Do not expect to catch the diabolo in this exercise; without it spinning it is very unstable in the air.

- **Discussion Points**

Are there any other toys that rely on friction to work?
What would happen if there was no friction?
When is friction a good thing? - soles of shoes, brakes, tyres …
When is friction a bad thing? - playground slides, engines …
What else operates on the same principle as throwing a diabolo? - bow and arrow.

Friction generates heat which is why we rub our hands together when they are cold.
Does friction always generate heat?
How was the first man-made fire started?
What can we do to reduce the friction between sliding bodies?

- **Extensions**

Further links can be made to KS3.1a through studying flywheels as energy stores, from early fly-press printing and cutting machines to push-and-go toy cars.

- **Links to everyday life**

Push-and-go toy cars use energy stored in a flywheel.
Slow-revving engines, particularly single-cylinder engines, rely on flywheels to function at all.

- **Other Resources**

The Complete Juggler by Dave Finnigan, Jugglebug 1991 ISBN 0-9615521-0-7

The pictures that accompany this module can be used as a basis for discussion about where the friction occurs, and in which direction the forces are acting and whether it has a positive or a negative effect.

When you are working the handsticks, where is the energy going?
What is making the diabolo spin?
Does the speed of the spin affect the height of the throw?
Where does the energy for the throw come from?
Why does the diabolo slow down if it is not continuously 'worked'?
Where does that energy go?

Friction between the string and the axle is absolutely critical to getting the diabolo working, as well as being the force most responsible for stopping it!

- **Curriculum Links**

Science 3.1a
3.1b
4c

- **Educational Objective**

The pupils will understand how friction is used to transfer the linear motion of a handstick into rotational motion of the diabolo. Also to understand that the energy they put in with the handstick is being 'stored' in the rotation of the diabolo; that the diabolo is a flywheel.

To understand that friction can be both an essential force as well as an impediment in mechanical systems.

To recognise that when throwing the diabolo, horizontally motion of the sticks results in vertical motion of the diabolo; i.e. in a plane perpendicular to the applied force.

- **Key learning**

Experimentation, hand-eye co-ordination, the ability to concentrate, problem-solving.

- **Materials Required**

1 x diabolo, 1 x pair of handsticks and string.
Projection of slides or video

- **Teacher Aware (Practicalities)**

There a no serious or unusual risks involved with this activity until the throwing and catching Step is reached. At this point there is a risk of being hit by a falling diabolo but the consequences of such an impact are practically insignificant.

At more risk are the fixtures and fitting around the room. Pay particular attention to light fittings, broken glass will present far more of a problem than a diabolo.

A diabolo is, essentially, a spinning object. Rolling it along the floor imparts some initial rotational momentum and the rhythmic 'snatching' of the string builds that momentum through its friction with the axle. For a right-handed person the diabolo will be spinning anti-clockwise in front of them, for a left-handed person the diabolo will spin clockwise.

Friction – Using a Diabolo

This ancient Chinese toy uses friction between the string and the axle to make it work.

- **Year 8/9 Key Stage 3**

- **Activity Description**

This activity is performed individually. Each pupil will require an area of at least 2mx3m of clear space. Most pupils will manage to achieve steps 1-3 after a few minutes of experimentation. Step 4 requires more concentration and focus but can be achieved by some in this age group.

Step 1 The pupil stands holding a diabolo hand-stick in each hand. A diabolo rests on the floor ‘astride’ the string with its axle pointing straight forwards. It should be noted that the diabolo is not directly in front of the pupil but slightly to one side – their dominant side. (fig.1)

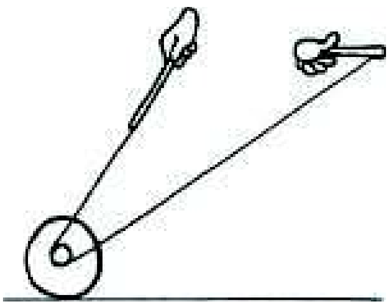


fig 1

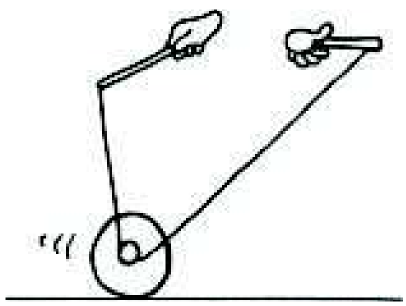


fig 2

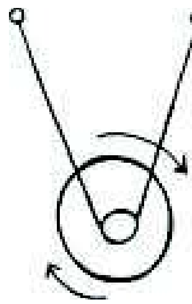


fig 3

Step 2) The pupil briefly rolls the diabolo along the floor, towards their feet (*fig 2)*, before lifting it up (*fig 3*).

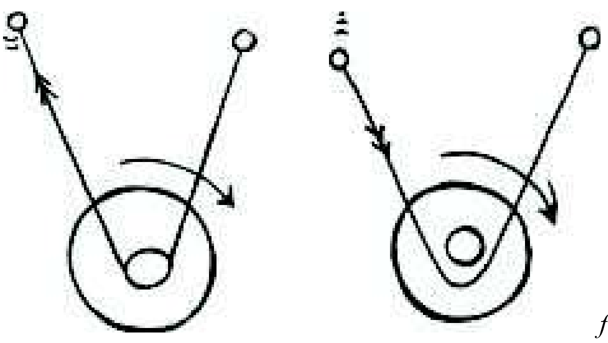


fig 4

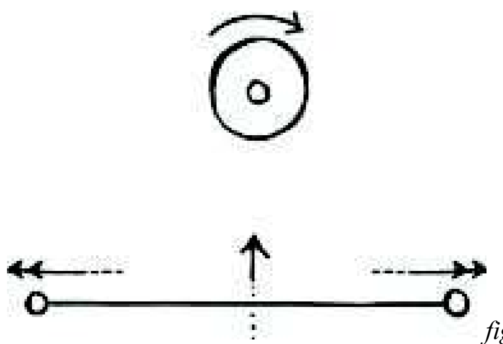


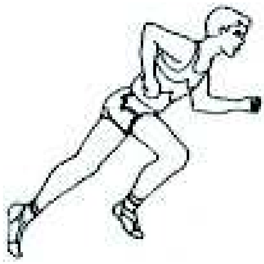
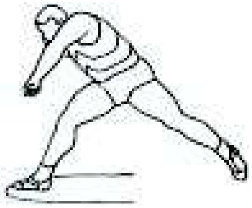
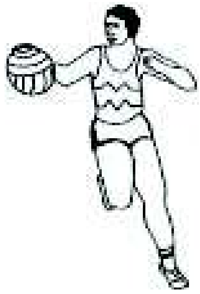
fig 5

Step 3 The dominant hand then begins ‘tapping’ up and down, ‘snatching’ the string in a rhythmic way, the other hand acts as a shock-absorber merely taking up the slack and keeping things tidy (*fig 4).* Try a rhythm of about 2 taps per second to begin with.

Step 4 The diabolo will begin to spin faster and faster. At some point the pupil will open their hands apart quickly, suddenly straightening the string and ‘flicking’ the diabolo straight up into the air (*fig 5*)

As it comes back down the pupil catches it on the string and immediately resumes Step 3.

- **Pictures**

		
A sprinter transfers a 'push' energy into the ground.	A thrower pushes into the ground and also transfers some of that energy into whatever is being thrown.	There are many energy transfers in basketball, the player is changing direction, the ball is bouncing …
		
Golf is definitely a 'hit', the duration of contact is momentary.	In tennis also the player has very little time in which to control the ball.	A gentle hit where accuracy is not a high priority.
		
This steam hammer exerts a huge, controllable force accurately and repeatedly.	The initial energy transfer is the push of the wind on the blades.	

- **Extensions**

There are flower-stick moves that only work because of the conservation of rotational momentum, particularly the 'propeller' where the flower-stick rotates in a vertical plane in front of you, controlled by only one handstick. Put aside a few days to learn this one!

Try to 'perform' step 5 making as little noise as possible.
Noise is wasted energy; do as little as possible to keep the flowerstick tick-tocking.

- **Links to everyday life**

The fact that energy is being transferred by everything to everything else all the time is beyond the scope of this module; here we are limiting ourselves to mechanical energy only.

Mechanical energy is transferred in every machine ever invented and every animal that ever lived; from the beating of your heart (a 'push' transfer) to scoring the winning goal (a 'hit' transfer).

'Hit' transfers:
All 'stick and ball' games; golf, tennis, hockey, batting in cricket … rely on the very accurate transfer of a precise amount of energy at exactly the right moment and in absolutely the right direction.

'Push' transfers:
Ten-pin bowling (the bowling, not the striking), blow-football, bowling in cricket, riding a bicycle, walking …

Is accuracy less important when pushing, compared with hitting or are the two unconnected?

- **Other Resources**

The Complete Juggler by Dave Finnigan, Jugglebug 1991 ISBN 0-9615521-0-7

The pictures that accompany this module can be used as a basis for discussion about how energy is being transferred, where the transfer is taking place and in which direction the forces are acting.

Hints & Tips

The handsticks should always make contact approximately half-way between the end of the flower-stick and the centre of the flower-stick (*fig.1*). There is no 'exact' position, it's all linked to where the flower-stick is, where you want it to go to and how much energy you need to give it at any given moment.

It works much more easily if you are relaxed when doing it - although relaxation can be more difficult to achieve than the exercise!

The handsticks must remain facing forward, and parallel, all the time, so the action is with the forearm and wrist combined, not just with the wrist.

If you are getting exhausted you are probably doing too much. Try to work with the forces of nature rather than against them, don't panic and give the flower-stick time to work.

Initially use the handsticks to 'catch-and-push' the flower-stick, rather than 'hit' it. When you have mastered step 5 then experiment with more of a 'hit' than a 'push'.

Which action gives you more control, a 'hit' or a 'push'?

- **Discussion Points**

What, in energy transfer terms, is the difference between a hit and a push?
Is one method of energy transfer inherently more efficient than the other?
In what common games is energy transferred by hitting?
In what common games is energy transferred by pushing?

How slow does a hit have to be before it becomes a push?
In a boxing match, are the contestants hit, or are they pushed quickly?

Does the density of the material make a difference?
Is it possible to hit a ball of candy-floss with a sponge?

It may be useful to think of a 'hit' is any situation where two bodies collide and an energy transfer occurs, and a 'push' being where the body imparting the energy is already in contact with the body receiving the energy.

A space rocket is pushed into space by its rocket motor; but what about a bullet fired from a gun, is it pushed or hit?

The equipment used in this exercise is extremely simple, as are most circus props; balls, sticks, string, hoops. There are no batteries, no moving parts, no on-board intelligence. Would the exercise have been as rewarding, or indeed possible at all, on a games console?

When step 5 is being 'performed', who or what is in control? Is the performer controlling the forces of nature, or are the forces of nature controlling the performer?

Does a low, fast spin require more energy than a high, slow spin?
Does the 'spin' element require more energy than the 'throw' element?
Does this depend upon the weight of the flower-stick?
Does this depend on the length of the flower-stick?
Is it possible to do a low, slow spin?

- **Curriculum Links**

Science 3.1a
3.1b
4c

- **Educational Objective**

To realise that the energy they put into the system has two components, an upward force and a turning moment. Apart from gravity, these are the only forces acting on the flower-stick.

By practical experimentation the pupils will understand how small variations in the force applied by each handstick can dramatically affect the movement of the flower-stick. The direction of the applied force determines what proportion of the energy is transferred into rotational momentum and what proportion into lift.

The pupils will draw on knowledge gained from this exercise to postulate about how things might function under other conditions, eg. if the flower-stick was heavier, longer …

- **Key learning**

Focus, concentration, analysis of visual observations and tactile feedback to be able to answer the suggested questions and make creative contributions to the discussion topics.

Successful achievement of step 5 requires, and therefore will have developed, a very practical understanding of the rhythms imposed by natural forces.

Pupils learn that to complete the exercise they must work with and reinforce the natural forces rather than work against them because ultimately it requires less effort and achieves better results – win, win!

- **Materials Required**

1 x flower-stick, 2 x rubber-covered handsticks
Projection of slides or video

- **Teacher Aware (Practicalities)**

The equipment comprises, essentially, three sticks. There are no specific health and safety considerations except for possible damage or injury due to pupils' bad behaviour.

Despite the apparent simplicity of the task, achieving Step 5 usually presents a challenge.

Gravity is a constant; the same for everyone everywhere regardless of age, location or academic achievement. The flower-stick is no easier for a professional circus performer than it is for anyone else, the same forces apply – the professional has just spent many hundreds of hours learning to work with them.

Energy Transfer – Using a Flower-Stick

An exercise to explore how the amount and direction of an applied force affects the motion of a body.

- **Year 8/9 Key Stage 3**

- **Activity Description**

Step 1 Hold the handsticks, one in each hand, horizontal, parallel, about shoulder-width apart and pointing away from you. Lay the flower-stick, evenly balanced, across both handsticks (*fig.1*).

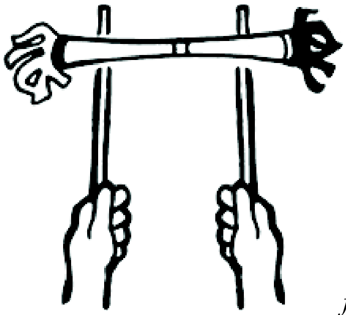


fig 1

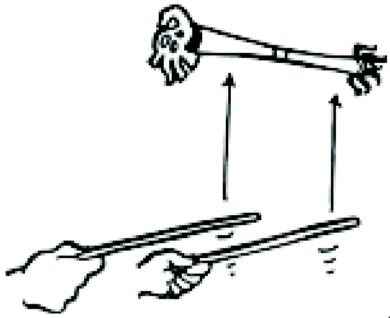


fig 2

Step 2 Throw the flower-stick into the air to about the height of your head keeping it horizontal and catch it again on your hand-sticks (*fig 2*). Vary the height of the throw but make sure that the stick remains horizontal.

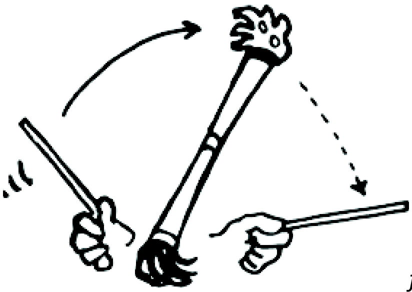


fig 3

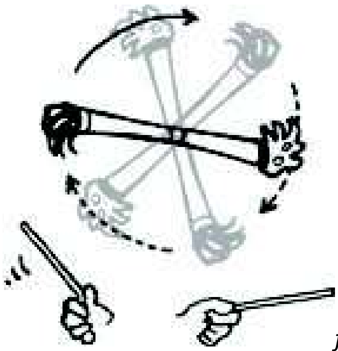


fig 4

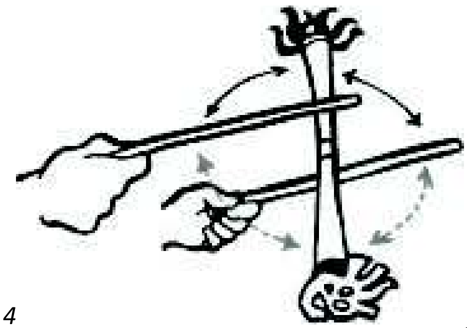


fig 5

Step 3 Throw the Flower-stick into the air with half-a-spin and catch it again on your hand-sticks (*fig 3*). Try a half-spin in the opposite direction.

Step 4 Throw the Flower-stick into the air with a full spin and catch it again (*fig 4*). Try a full-spin in the opposite direction.

Step 5 Try a half-spin in one direction *immediately* followed by a half-spin in the opposite direction *without catching* between the spins. With practice you should be able to get the flower-stick to tick-tock back and forth in a vertical plane in front of you (*fig 5*).

Try varying the height of the throws and the speed of the spins, but always with enough control to be able to catch the flower-stick.

- **Pictures**

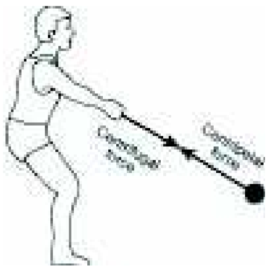
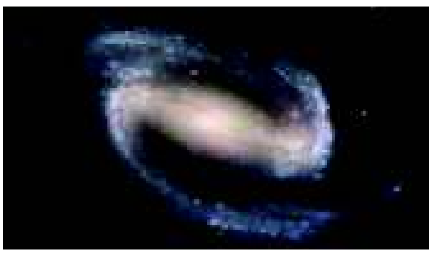


Diagram showing the Centrifugal force – the 'pull' exerted by the ball, and Centripetal force – the equal and opposite 'pull' exerted by the athlete.	A speed-governor typically used on steam engines. As the shaft rotates the balls swing out and rise, closing the steam valve.	A salad-spinner - a spin-dryer for food.
		
Medical centrifuge typically used to separate blood components and in DNA analysis.	Horizontal centrifuges are used in many industries from chemical, to building materials. This model comes up to 1.8m diameter.	A cross-section of a modern commercial application of the effects of centrifugal force.
		
This fairground ride, the Meteor, relies entirely on centrifugal force to prevent the riders from falling out.	The Whip maximises the effects of centrifugal force for the riders.	This is the type of centrifuge that NASA uses to simulate extreme gravity conditions.
		
A spiral galaxy as seen from Hubble.		

- **Extensions**

There are a number of tricks that can be performed once the spinning has been achieved: a simple vertical throw and catch – just the plate, not the stick as well, a throw to an empty stick held in the other hand, a throw and catch on the opposite end of the same stick – this is quite a quick move requiring accuracy too.

Take the case of an olympic hammer-thrower. As the athlete rotates and the hammer swings round, the athlete is pulling the hammer towards him with a 'centripetal' force that exactly matches the 'centrifugal' force exerted by the hammer. When the athlete lets go, the centripetal force is lost, centrifugal force takes over, and the hammer flies away.

- **Links to everyday life**

Centrifugal force is a phenomenon that has been recognised and harnessed for millennia, long before it was ever understood scientifically. It is the force behind whirlpools and is responsible for the shape of our galaxy and also, possibly, for black holes.

Centrifugal force is utilised in inertia-reel seat-bet mechanisms to make them lock-up in the event of an accident.

Centrifuges are used in science to separate compounds, in medicine to isolate components in blood and in the home to dry clothes and salad.

- **Other Resources**

The Complete Juggler by Dave Finnigan, Jugglebug 1991, ISBN 0-9615521-0-7

The pictures that accompany this module can be used as starters for discussions about rotating objects and the forces that they exert and experience. From flywheels to gyroscopes, our modern life relies on these fundamental forces of nature.

- **Curriculum Links**

Science 3.1a
3.1b
4c

- **Educational Objective**

Pupils are able to describe how centrifugal force 'lifts' the plate from vertical to horizontal. They understand that the energy they put into the system is stored in the rotation of the plate.

They recognise the effect of friction between the plate and stick when speeding it up, and also the effect of friction when the plate is spinning on top of the stick. The pupils will be able to explain why the plate slows down and how the energy is dissipated.

- **Key learning**

Experimentation, delicate hand-eye co-ordination, concentration, problem-solving.

- **Materials Required**

1 x spinning plate, 1 x spinning plate stick
Projection of slides or video

- **Teacher Aware (Practicalities)**

The equipment includes a pointed stick; obvious safety precautions should be taken.

As the pupil begins to move the stick in circles, it imparts a centripetal force on the rim under the plate. What this force is trying to do is to push the rim away from the centre of the plate. The only way this can happen is if the plate rises to the horizontal – which is precisely what happens. When the plate is horizontal, as the pupil increases the speed of the circles the friction between the plate and the stick allows the transfer of this energy into the plate, which then also speeds up.

Hints & Tips

All the movement is in the wrist, no other part of your body need move (breathing excepted!).
The use of centrifugal force needs to be subtle and controlled.
Hold the stick lightly so that you can 'feel' what is happening.
This is a skill that relies on fine control and tactile feedback, not brute force.
Unfortunately it is very easy to do it wrong, most commonly illustrated by the stick remaining almost still and the plate hurtling round it uncontrollably. If the wrist is stiff or the stick is not moving in circles or if the plate is not rotating *about its own centre* then more practice is required.

- **Discussion Points**

Would a lighter or a heavier plate be easier to spin?
Which plate would store most energy?
Which plate would spin for the longest time?
Is it best to have a lot of friction between the plate and the stick, or as little as possible? (Think about how you speed it up as well as what makes it slow down).

Centrifugal Force – Plate Spinning

An investigation into the use of centrifugal force when spinning a plate on a stick.

- **Year 8/9 Key Stage 3**

- **Activity Description**

Each pupil will attempt to get a plate from hanging motionless, to spinning on the top of a stick using only the rotation of their wrist.

Step 1 The pupil stands relaxed with a stick held vertically in their dominant hand; hanging from the top of the stick is a spinning plate (not spinning!) (*fig 1*).

Step 2 The pupil then begins to 'draw circles in the air' with the top of the stick, whilst keeping the base of the stick in the same point in space. The movement of the stick describes an upside-down cone with the point of the cone in the pupil's hand (*fig .2*).

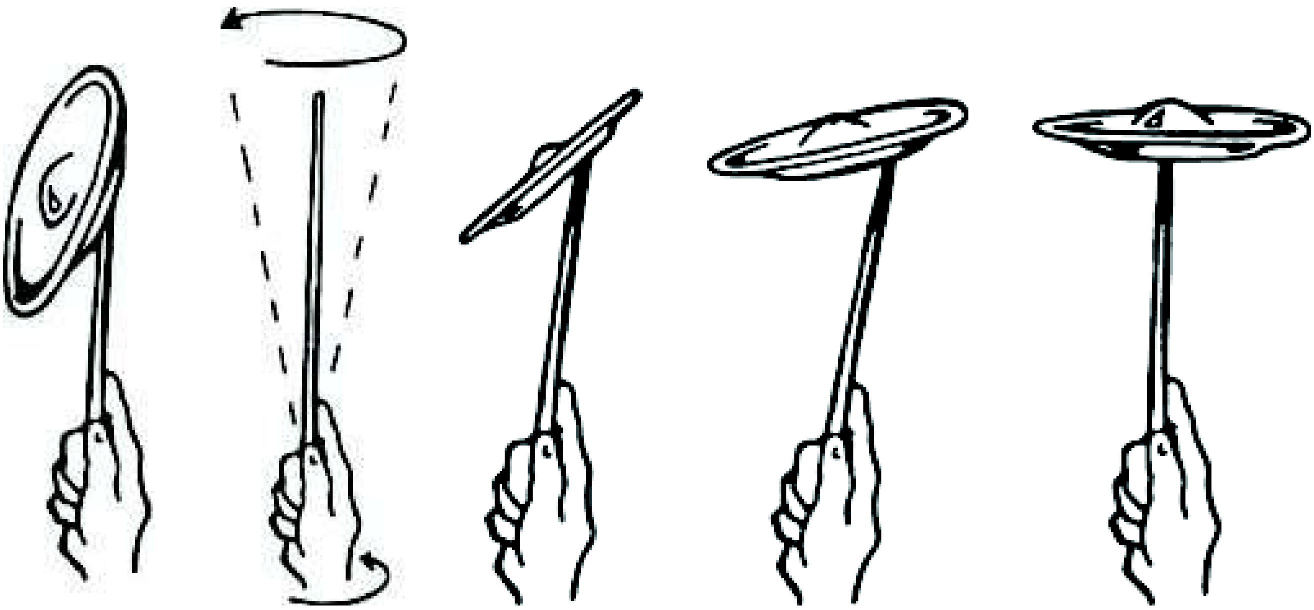


fig 1 *fig2* *fig 3* *fig 4* *fig 5*

Step 3 As this happens the plate begins to rise to the horizontal plane and for a while the pupil is 'pushing' the plate round in circles, quicker and quicker (figs 3 & 4). Make sure that the centre of the plate remains directly above the wrist.

Step 4 At some point the stick is abruptly stopped and aimed at the centre of the rotating plate. At this stage the 'trick' is over and the plate is merely spinning on the top of the stick (*fig 5*).

It is very important not only to watch what is happening to the plate, but also to feel what is happening in your wrist. When you have learned to do it, try it with you eyes shut.

5. Juggle one ball from one hand to the other and back. Add a clap in between throw and catch. Make sure the quality of the throw and catch are not disturbed by the clap action. Throw higher to make time for 2 or 3 or more claps. Concentrate on the high point of the arc of the ball and NOT on the ball in your hands. Do the same exercise but follow the movement of the ball through hand, the air and hand again. You will be tracking a horizontal figure 8, or infinity sign as you follow the ball's trajectory.

   Juggle one ball from one hand to the other and back. As soon as you have thrown the ball, snap your fingers before the ball arrives in the other hand. Keep the ball juggling from hand to hand with a finger-snap from both hands.

6. Yawning is a waking-up exercise and not a sign of sleepiness. The yawn is a sign that the body is trying to wake up. Yawning is an exercise in letting-go of tension. Brain-gym people call it the 'energy yawn' and it is one of the exercises that relieves the stress that interferes with learning & performance. Following yawning, simply massage the muscles around the junction of the jaws.

7. Close your eyes, extend you arms long out to the side, extend the forefinger, bring one forefinger and arm slowly in towards the face and touch the very end of your nose. Do this three times with each arm, alternating arms.

8. Stand on one leg, knee raised on the other leg. Relax by breathing calmly. Close your eyes, remain in balance and count out-loud backwards from 100 in threes, starting with 100. This will be difficult at first. With practice see how much the count down improves.

9. Let you arms hang by you sides, stand up straight. In the same motion bring your hands up in an arc and touch your left shoulder with your right hand and your right shoulder with your left hand, so that your right arm is underneath your left arm. Relax again, arms by your sides. Repeat action but with your right arm on top of your left arm, so that you alternate the arm on top.

10. Position your hands, palms facing each other about 6" apart. Curl the fingers of one hand and bring it into contact with the open palm of the other hand. Separate your hands and uncurl your fingers. Curl the fingers of the opposite hand and bring the hands together again. Repeat this process and slowly get faster until you do it as quickly as possible.

- **Teacher Aware**

For all these exercises breathing calmly and slowly is the key.

When you breath in, let you lungs expand downwards (do not raise your shoulders) and let you diaphragm expand downward and out so that you belly swells a little. True and calm breathing comes from the diaphragm and not from raising the shoulders. You need to fill the lungs with air from the bottom upwards and not from the top downwards. Breathe in slowly and deeply, hold the breath for a second or two and when you release the breath let it flow unhindered out of your mouth almost with a sigh of letting go.

Brain and Body Awake – Warm-Up Exercises

A sort series of exercises to prepare oneself for learning

- **Suitable for able-bodied people of all ages**
- **Activity Description**
-

Some of these exercises have been used by actors and circus artists for decades, possibly hundreds of years, as part of their standard warm-up for rehearsals and performances. They are also used regularly in corporate management training workshops to help clear the mind of the stresses of the day. These types of exercise stimulate the left and right sides of the brain, promote relaxation, increase blood-flow to the brain, improve concentration and focus and generally prepare the mind and body for learning and teaching.

The only prop required is one juggling ball, although we do suggest that juggling with 3 balls in the 'cascade' pattern is an excellent brain wake-up exercise.

This set of exercises, presented here in no particular order, offers a 15 minute daily routine that can be run in private or in a small group.

- **The Exercises**

1. Stand on your LEFT foot and raise your RIGHT foot into the air by bending your RIGHT knee. Draw a CLOCKWISE circle with your raised RIGHT foot. At the same time draw a large number '6' in the air with your RIGHT hand.

   Stand on your RIGHT foot and raise your LEFT foot into the air by bending your LEFT knee. Draw a COUNTER-CLOCKWISE circle with your raised LEFT foot. At the same time draw a large number '9' in the air with your LEFT hand.

2. Hold two hands out in front of you, arms bend and elbows by your side. Point your right hand index finger forward, hold you left hand thumb upwards. Your right hand is pointing in a forward direction and your left hand is making a positive thumbs-up sign. Now in one move switch the two around, so that you right hand is making the thumbs-up and your left hand is pointing in a forward direction. And switch back. Try to switch between the two smoothly and regularly.

3. Stand up straight. Extend your arms out wide to either side of your body and at shoulder height, so your body is making the shape of a 'T'. Turn your hand at the wrist 90° forwards, make a fist and then point index finger forward, Close your eyes. Keeping the arms fully extended, bring the fingers forwards and together, try to get your two index fingers to touch tip to tip. Don't peek!

4. With your right hand index finger make the shape of a triangle in front of you in the air. Draw it in a clockwise direction. Stop. With your left hand index finger make the shape of a circle in front of you in the air. Draw it in an anti-clockwise direction. Stop. Now try to make both different shapes at the same time. Vary with other shape patterns – square and circle, triangle and square. Remember to try different directions of motion i.e. draw the triangle anti-clockwise and clockwise, draw shapes with left and right hands. Be careful to keep the lines straight and the circles curved.

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Foreword

Space Circus was conceived in 2006 in response to Yorkshire Forward, the Region's Development Agency, STEM (Science, Technology, Engineering & Maths) commissioning round of the same year. The main aims of the Yorkshire Forward funding were to increase attainment, progression; skills and employability in STEM subjects throughout the Yorkshire and Humber region and Space Circus became one of 10 projects to receive funding.

The concept of Space Circus was very simple; to make education entertaining and in doing so, to inspire young people to achieve more! The theme of Space was selected as the "vehicle" because of its universal appeal to boys and girls and the popular perception that no other theme offers as much opportunity to interest, motivate and influence young people.

The Space Circus approach involved a series of interventions targeted at upper Key Stage 2 and lower Key Stage 3 pupils. At the core of the project was a touring theatrical show involving 3 inflatable Pods which provided a truly immersive experience for the audience. The show was supported by CPD training for teachers, funding for Out of School Hours clubs and family engagement activities, competitions, and Space Extravaganza days.

Space Circus "finished" in March 2010. By this time the show had been performed to over 16,000 Pupils and over 1000 teachers had received CPD training. The resource contained in this pack was developed and delivered as one of the CPD courses during the project and now it represents an opportunity to sustain the legacy of Space Circus for the future. One of the questions I was always asked during the life time of the project was "where is the Circus in Space Circus?" The answer now lies within this resource pack.

Space Circus would not have been possible without the help and contributions of many organisations and individuals too numerous to mention here and a big thank you goes to all those involved. I sincerely hope that all who use this resource enjoy the activities and in doing so, ensure that it fulfils the original ethos of the project…to make education entertaining.

Partners in Innovation Ltd – Centre of Excellence, Hope Park, Bradford, BD5 8HH.

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SpaceCircus
education as entertainment

The Science of Circus