Defying Gravity - Teacher Notes

Safety First

The magnet used in this activity is quite strong. Care should be taken when handling the magnet in close proximity to other magnets or to objects made from iron or steel. The strength of attraction can cause these objects to move together rapidly, potentially trapping fingers or skin. (The magnet does not need to be handled during the activity.) Strong magnets can adversely affect heart pacemakers. Do not place close to credit cards. Care should also be taken when assembling the structure as you will need to use scissors and other sharp tools.

About this Activity

What you are going to make in this activity is a fascinating and addictive toy. I have yet to find anyone who is not completely mesmerized by it. In some respects it is more like an executive toy than a children's science experiment, and it will provide hours of entertainment – for you and the children! However, it also offers a very interesting way to explore magnetic attraction – and in particular the competing forces of gravity and magnetic attraction.

We will use it to explore:

- Magnetic attraction;
- The challenge of measuring quantities in awkward situations;
- The importance of measuring quantities more than once;
- Balanced forces.

Before You Start

Equipment needed:

- Large strong magnet – approx 12mm diameter by 2mm thick. This is the largest of the magnets supplied in the Fun with Forces pack.
- Empty crisp tube (e.g. Pringles).
- Pencil.
- Small paperclip.
- Cotton or fine thread.
- Sticky tape.

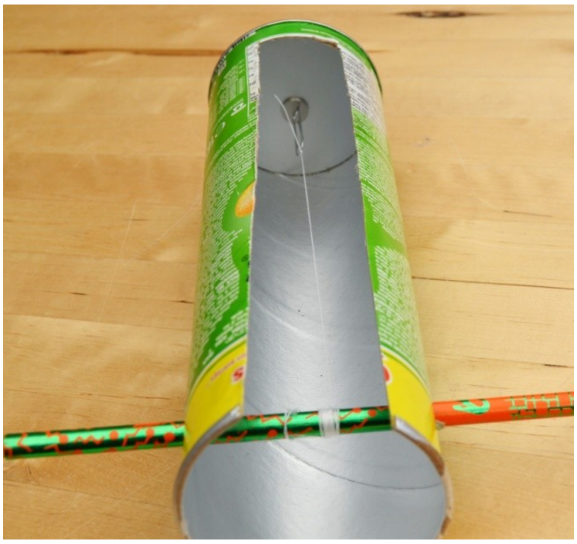
Preparation:

Assembly takes about 10 minutes – and a little patience.

- Cut a long slot in the side of the crisp tube, as shown in the picture below. The slot should be about 5cm wide, and should extend from the open end of the tube almost as far as the metal base.
- Use a sharp pointed object to make a small hole in either side of the tube close to the open end. Now push a pencil all the way through the two holes. The pencil should stick out on either side (see photo).
- Cut a length of cotton thread about 40cm long. Tie one end of the thread to the paperclip, and use the sticky tape to fasten the other end of the thread to the middle of the pencil.
- Place the magnet carefully inside the crisp tube so that it is in the middle of the

base of the tube. The magnet should be attracted to the base, so there is no need to use any glue. (I have also made these toys using clear plastic tennis ball tubes. The advantage is that everyone can see inside the tube – so you don't need to cut the slot in the tube. The disadvantage is that you need to use some strong glue to fasten the magnet in place.)

You are now ready to do the gravity-defying experiment.



Worksheets:

There are 3 worksheets to accompany this experiment:

- **Defying Gravity p1** looks at measuring the maximum separation between the magnet and the paperclip;
- **Defying Gravity p2** considers what happens if you change the size of the paperclip or the strength of the magnet;
- **Defying Gravity p3** examines the forces on the paperclip.

You can use more or less any combination of these worksheets, e.g.

- **p1** alone;
- **p3** alone;
- **p1** and **p2**;
- **p1** and **p3**;
- **p1**, **p2** and **p3**.

How to Defy Gravity

To use your new toy:

- Place the paperclip inside the crisp tube so that it becomes attached to the magnet. Slowly turn the pencil until the thread becomes taut.
- Stand the crisp tube upright so that the metal base is at the top. The paperclip is now at the top, held in place by the magnet.
- Very slowly, turn the pencil so that the thread becomes shorter. The paperclip pulls away from the magnet by just a millimetre or so. This looks incredible! The paperclip stays up in the air – as if by magic! (You can very gently touch the thread – and feel that it is pulled taut.)
- Continue to turn the pencil very slowly – so that the gap between the paperclip and magnet becomes larger. How large can the gap become before the paperclip falls? (If you do this very carefully, you may notice that as the gap becomes larger, the

paperclip starts to spin rapidly. This tends to happen just before the paperclip falls.)

Measuring the maximum distance between the paperclip and the magnet
(Defying Gravity p1)
This is a very difficult task because as the paperclip moves further from the magnet, the slightest nudge will cause it to fall – so holding a ruler inside the tube to measure the distance is not very practical - unless you have very steady hands!

Challenge the children to come up with an idea for measuring the distance. If they have several ideas you could then ask them to discuss the merits of each scheme. It may be worth trying out each suggestion so you can see which one works best. These are some of the ideas that I have used:

- Stick a short (15cm) ruler to the back of the crisp tube before you do the experiment. You can then align the top of the paperclip with the marks on the ruler. One problem with this method is that you have to ensure that your eyes are on the same level as the top of the paperclip. If you look at a slightly different angle you will obtain a different measurement. (Scientists call this a **parallax** error.) Also you will have to rely on one person to take the reading – as it is difficult for more than one person at a time to see into the back of the tube.
- Stick a measuring tape down the outside of the crisp tube, next to the slot – and align the top of the paperclip with the marks on the tape. Again, this can suffer from parallax errors, because the reading will be different if you look at it from different angles. However, this does have the advantage that several people can see this at the same time. Depending on their position, they may each come up with a different measurement – but at least you can take an average of their readings.
- Possibly the most satisfactory method is to allow the paperclip to fall. Now turn the tube the other way up – so the magnet is at the bottom and the paperclip is hanging down inside the tube. (If the paperclip is now touching the magnet, you have inadvertently allowed the thread to become unwound by one turn.) You can now put a ruler inside the tube and measure the distance between the magnet and the paperclip. (Of course, this method slightly overestimates the maximum separation – because we are measuring the distance after it falls, rather than just before it falls – but at least this is a systematic error, i.e. the error should be about the same for every measurement.)

Making more than one measurement (Defying Gravity p1)
Encourage the children to discuss why they think it is important to make several measurements of the maximum separation. In this experiment the two main reasons are:

- The difficulty in measuring the distance means that in any one instance the children may disagree about the distance that they measured (particularly if the measurement involves parallax errors, as discussed above).
- When the paperclip is just about to fall it is susceptible to very small forces – such as a draught of air, or someone nudging the table. So if you repeat the experiment several times you may get different answers each time.

Once you have several measurements, you can then determine the average distance. Depending on the mathematical ability of the children you can either:

- Add up all the measurements and divide by the number of readings – to find the

mathematical 'mean'.
- Or simply write the measurements in order, from smallest to largest, and take the middle value.

What happens if you change the size of the paperclip? (Defying Gravity p2)
If you use a larger paperclip – one which has more mass – the force downwards is larger, so the paperclip will fall when it is at a much closer distance from the magnet. (See below for more information about the forces on the paperclip.)

Ask the children to predict what will happen – and then get them to carry out the experiment to see if their prediction is correct.

What happens if you change the magnet? (Defying Gravity p2)
We have been using the largest of the magnets supplied in the Fun with Forces pack, but there are also some smaller (and weaker) magnets, which are used in the Magnetic Pendulum experiment. (There will be several of these in the pack.) What will happen if you use one of these magnets?

Since the small magnet is weaker, the paperclip will fall when it is at a much closer distance to the magnet. (Make sure you use the small paperclip in this part of the experiment.)

Repeat your measurements using two of these small magnets joined together. Try again using 3 magnets, then 4. As you add more magnets, the maximum separation between the paperclip and the magnet increases. So using more magnets effectively creates a stronger magnet. (Note – as you add more magnets, the lower surface of the magnet moves further from the base of the crisp tube – so you will need to make sure that you are measuring the distance from the paperclip to the magnet, not to the base of the crisp tube.)

What happens if you change the polarity of the magnet?
These disc magnets have a north pole on one face and a south pole on the opposite face. So to change the polarity of the magnet (e.g. to switch from using the north pole to the south pole) you simply turn the magnet over. This should not make any difference, but it may be worth trying. (In fact, since you should get exactly the same result with both poles of the magnet, what you are really measuring is the error in your measurements.)

What are the forces on the paperclip? (Defying Gravity p3)
This is not quite as simple as it seems. Many people draw two forces:
- An upwards force – caused by the magnetic attraction between the paperclip and the magnet;
- A downwards force – due to gravity.

Many children (and adults) are satisfied by this explanation. If so, you do not need to read any further.

OK, so I am guessing you want to know more. Consider this scenario:
- Let us suppose that the paperclip is 5mm from the magnet. There is the upwards force of attraction from the magnet and the downwards force of gravity on the paperclip.
- Now we shorten the thread slightly, so that the separation is 6mm. Since we have moved the paperclip further from the magnet, the force of attraction from the

magnet must be weaker than before. But the downwards force is the same as before.

- So if the two forces were balanced when the paperclip was 5mm from the magnet, then the paperclip should fall when it is 6mm from the magnet. But of course, our argument would be the same whether the paperclip was initially 1mm or 15mm from the magnet – if we move the paperclip away by any arbitrarily small amount, the attractive force decreases, so the paperclip should always fall!

The solution to this conundrum is that there must be a third force – **the tension in the thread**. It is these three forces that are balanced:

- The upwards force due to the magnetic attraction of the paperclip is equal to the **sum** of the downwards forces (gravity plus tension).

If we move the paperclip further away from the magnet, the (upwards) force of magnetic attraction is reduced, but also the downwards force of the tension in the string is reduced by exactly the same amount.
It is only when the paperclip is at the maximum distance from the magnet that we only have to think of 2 forces. At this point the tension is virtually zero, so the force is magnetic attraction is equal to the force of gravity. If we make the thread any shorter, the force of magnetic attraction will be less than the force of gravity – so the paperclip falls.

If you are still not convinced by the reality of this third force, then try this:

- Unwind the thread so that the paperclip is some distance from the magnet, but not so much that it is just about to fall.
- Using a very sharp pair of scissors, cut the thread.
- What happens? The paperclip shoots upwards and sticks to the magnet.

At the point when we cut the thread, the upwards force from the magnet must have been much stronger than the downwards force of gravity. The only thing that stopped the paperclip from being pulled up was the thread. So it must have been the downwards force of the tension in the thread which balanced the forces and stopped the paperclip from moving.

I will leave it up to you to decide how much (if any) of this explanation you wish to share with the children.