



# **Design & Technology**

# **DANCING TOY**

# **PROJECT**



**SMART MATERIALS**  
**Polymorph & Muscle wire**



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## **Introduction**

This project Light Stitches Book 4 Smart Materials Polymorph & Muscle Wire - Dancing Toy Project has been designed and aimed specifically at year 8's as an introduction to product design to encourage the mixing of different D&T elements.

This project would be ideal as a starter project going into GCSE work. The project could also be done as a manufacturing style with group work. Choice obviously, as ever depends on funds available, polymorph for a whole year group can work out expensive but due to the fact that smart materials are being used in the way of muscle wire, the needs of the students are still being met even when using acrylic or good old MDF to make the body of the toys. But to take on a polymorph version for a display piece to show off the students' ability would be well worth it. You could also bear in mind that Smart materials like polymorph and muscle wire can be re-used again and again.

In these days of tight budgets these items could also be made by a class as group work. By dividing the class into 3 groups and each one working on each design and its development as a group with a presentation to the rest of the class at the end, this way only 3 items are made instead of over 20 thus reducing costs.

Any specialized components you may require such as muscle wire is available from Light Stitches or Rapid electronics.

Please see our website for the latest projects. We hope you find all the information and resources useful.

Any problems please contact us at [sales@lightstitches.co.uk](mailto:sales@lightstitches.co.uk)

## Brief history of muscle wire

Discovered in 1932 by Arne Olander, the Swedish researcher noticed the recovery abilities of gold– cadmium alloy and realised its potential to create motion. The study of this unusual alloy continued by various institutions and intellectuals until the discovery of indium titanium SMA, but both these discoveries proved problematic, as both relied on gold. The expense of gold limited the research carried out until in 1963 the announcement of nitinol (nickel and titanium) by W J. Buehler at the US Naval Ordnance Laboratory, this initiated a new wave of research and discovery which continues to the present day.

NASA researched memory alloys to control satellite antennas, that when exposed to the sun rays would unfold by the heat of the sun, most research focussed on the memory alloys ability to move or contract with temperature. Research included among other things controlled greenhouse windows and safety valves.

## Underlying technology

Muscle wire, also known as smart wire, more commonly known as nitinol wire, which is the name for very high performance, shape memory alloy, actuator wires. It is made of nickel-titanium.

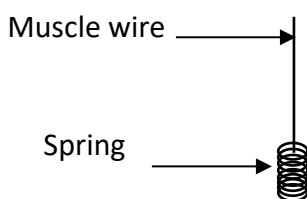
**NI** - Nickel. **TI** - Titanium. **NOL** - Naval Ordnance Laboratory. **NITINOL**

These small diameter wires have been specially processed to have large, stable amounts of memory strain for many cycles. In other words, they contract like the fibres of a human muscle, when electrically driven (hence the name muscle wire)

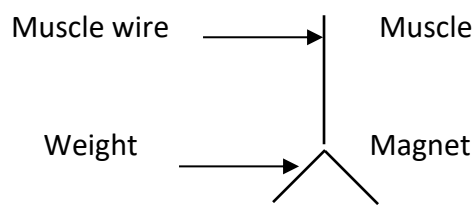
The ability to shorten in length approximately 5% occurs because both nickel and titanium atoms are present in the alloy in almost exactly a 50% 50% ratio which dynamically change their internal structure at certain temperatures. The idea of reaching higher temperatures electrically came with the light bulb, but instead of producing light these alloys contract by 4 to 5% of their length when heated and can then be easily stretched out again as they cool back to room temperature.

Stretching muscle wire to its original length can be achieved by the use of a spring or small weight

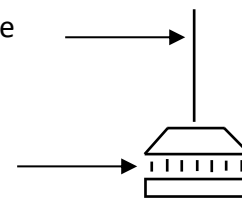
**(This opposing force, used to stretch the wire to its original state, is called the bias force)**



**Normal Bias Spring**



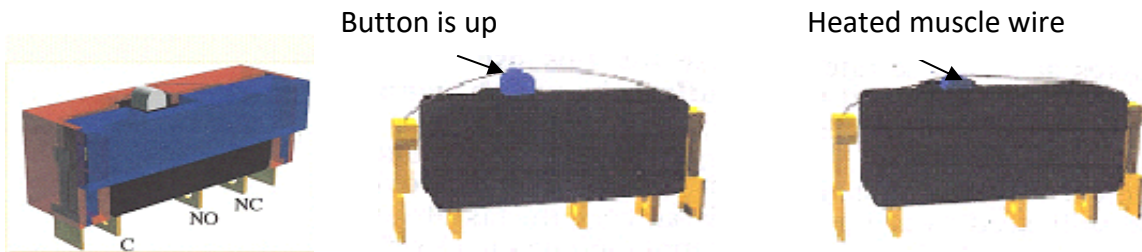
**Dead Weight Bias**



**Magnet Bias**

The main point is that movement occurs through an internal “solid state” restructuring in the material that is silent smooth, and powerful.

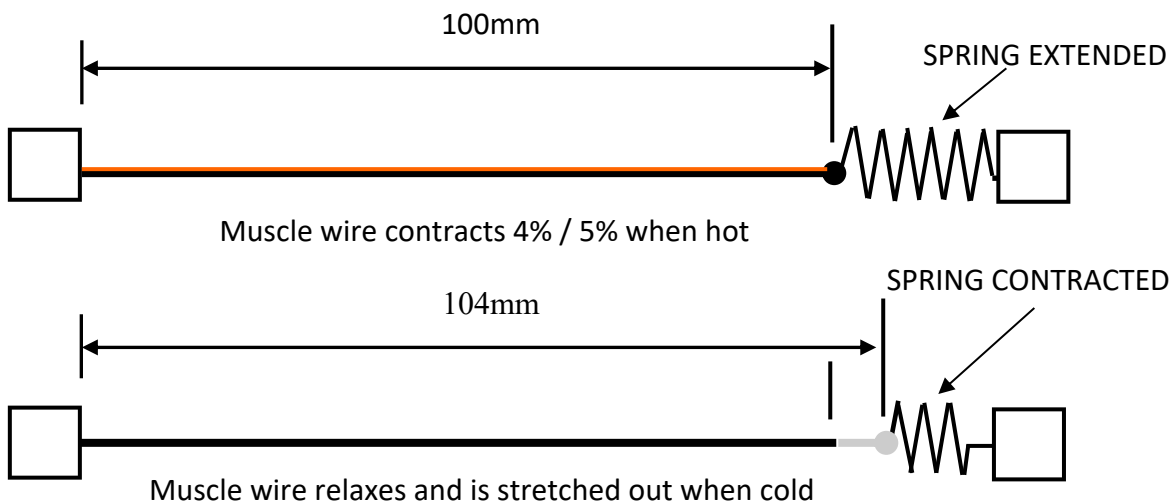
Many of the tasks currently being done with small motors or solenoids can be done with muscle wire, which are smaller and less expensive. A simple relay can be achieved as shown below.



A simple add on to a standard switch, this cover enables one to make an inexpensive relay, by holding muscle wire in place over the push button, when the wire is heated it will contract 5% and activate the switch as shown above.

By substituting different sizes of muscle wire, one gets a different current rating to work with.

As muscle wire contracts when heated the same principles can be used as safety cut off / sensor, examples hair dryer cut off /sensor, heater cut off /sensor, Mechanical Voltage Regulator, Mechanical Current Regulator.



**Contraction time of muscle wire is directly related to current input**

But a simple rule can be applied to prevent overheating, by observing the muscle wire when the current is shut off, the wire should immediately begin to cool and relax to its original length. If it does not begin to relax and elongate under a small bias force when the power is cut, then the wire has been needlessly overheated.

**Simple visual observation is all that is needed to prevent overheating.**



### Technical data

Diameter Size ( Inches )	Resistance ( Ohms/Inch )	Maximum Pull Force (grams)	Approximate Current at Room Temperature ( Ma )	Contraction Time (seconds)	Off Time 70 c (seconds)
0.004	3.0	150	180	1	0.8
0.005	1.8	230	250	1	1.6
0.006	1.3	330	400	1	2.0

### Useful benefits of muscle wire

**Inexpensive** (fraction of the cost of motors or solenoids)

**Silent** (unlike motors, gears and cams, the wire produces no grinding sounds or clicking)

**Reliable** (used properly it will work for a long time some products have run 100,000,000cycles)

**Durable** (is highly corrosion resistant so can be used in rain and snow and requires no lubrication)

**Space saving** (so small it can be used where solenoids and motors cannot)

**Weight saving** (desirable over motors or solenoids as wires are thousands of times lighter)

**Smooth movement** (molecular structure allows a smooth movement)

**Temperature driven** (for many products activation by heat is desirable)

**Fast** (With electricity can operate in .001 seconds)

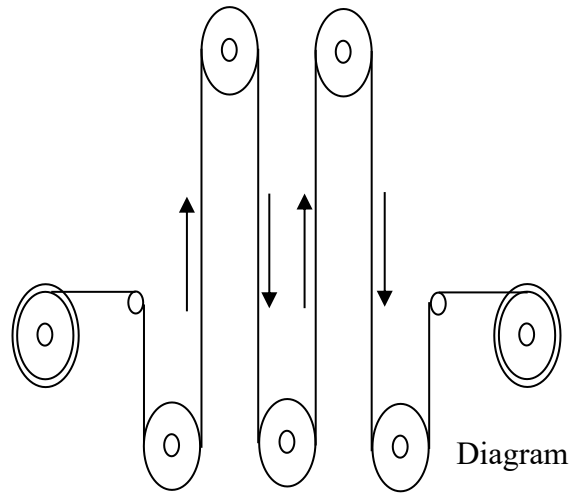
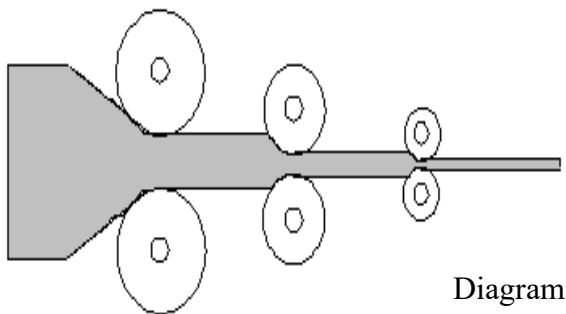
**Forgiving alignment** (Flexible and can be wrapped around and do not require straight)

**Long life** (Muscle wire could function for millions of cycles if used correctly)

**Strong force** (capable of lifting thousands of times their own weight)

### How muscle wire is manufactured

1. Equal amounts of nickel and titanium are measured and melted into a block. (this means equal atomic amounts not actual weight, 50% nickel atoms and 50% titanium atoms)
2. The solid block is rolled at a low temperature to the specified diameter as shown in diagram A
3. Wires are annealed and trained on cycling equipment as shown in diagram B
  - a. (annealing process explained below)



### Annealing and Pretraining process explained

How to train nitinol shape memory alloys to remember its original shape or size. The muscle wire is formed at a low temperature as shown in diagram A. When muscle wire is clamped in the position (Diagram C) and professionally heated past its transformation temperature to its annealing temperature 540 c and allowed to cool, muscle wire will acquire the annealed shape as shown in Diagram D.

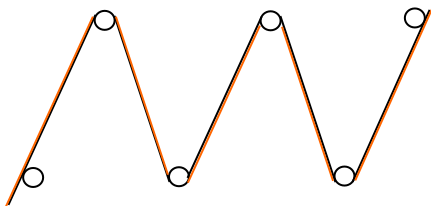


Diagram C heated muscle wire

Clamped solidly to prevent movement.  
 Heated past its transformation temperature to its annealing temperature 540 c

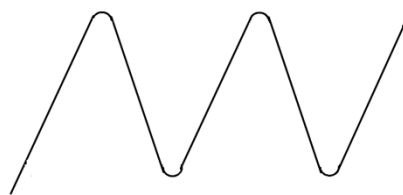
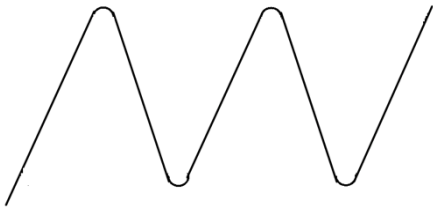


Diagram D Annealed muscle wire

Annealed shape as shown above, can easily be straightened and when heated will return to its annealed shape.

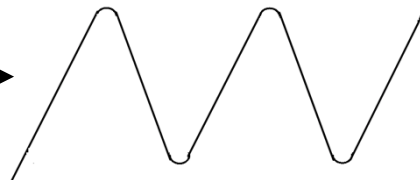


Annealed shape

The annealed shape can easily be straightened/ stretched into position and will remain in the chosen position until heated. Example if annealed muscle wire was straightened as shown below and then heated it will return to its annealed shape.



Straightened Muscle wire



Heated Muscle wire

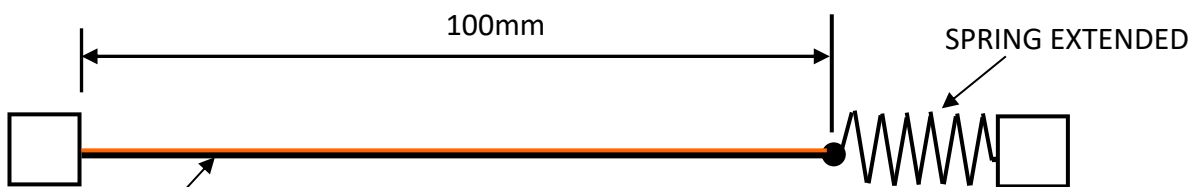
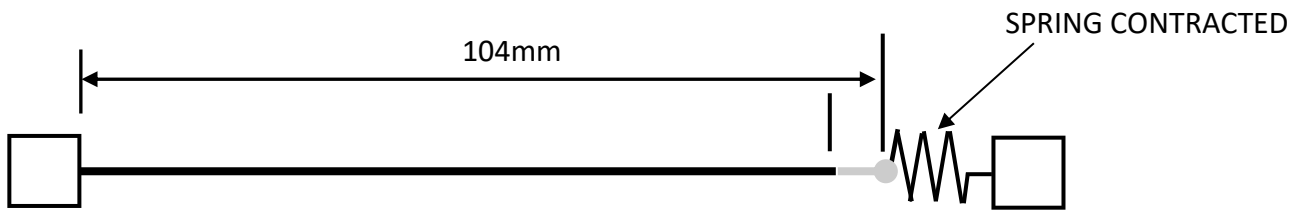
**Forces**

Nitinol shape memory alloys can exert a force of 600 million newtons per square meter, equivalent to 40tons per square inch.

The force a muscle wire can produce depends on its composition, size and training, although force is directly related to the cross sectional area or diameter of the muscle wire.

The most force nitinol wire (muscle wire) is able to produce is 600 MPa (megapascal, which is a million Newtons per square meter)

The annealed 100mm nitinol (muscle wire) is professionally stretched to a length of 104mm, the wire will stay at 104mm until heated, at which point the muscle wire will return to its annealed length of 100mm as shown below.







## **Future research of muscle wire**

The benefits of muscle wire include size, cost, quiet operation, high resistance to corrosion, which all help to simplify the design process. The capability of muscle wire to lift thousands of times its own weight and using multiple wires can exert a great force, is the key to its future developments.

Using groups of muscle wire uses the same principle as the human muscle. A lot of medical research has undergone into artificial limbs consisting of groups of muscle wires, electronics, which could then be covered and disguised as a human limb.

Size is another benefit muscle wire has over conventional approaches as more surgeons perform operations using fibre optic cameras and small surgical tools, advanced surgical tools would extend the surgeons capabilities during operations.

Due to its long life, size and ability to lift thousands of times its own weight, the future will see muscle wire used similar to the human muscle, with the ultimate goal being the creation of an artificial life form similar to the robots portrayed in science fiction books and films.

## **Sample application for muscle wire**

(also known as nitinol wire, actuator wire)

### **Electronics**

Retrofit Switch to Relay (as shown P4 )  
Safety Cut Offs  
"Clean" Actuators  
Micro Circuit Breakers  
Remote Switch Controllers  
PC Mount Relays  
Chassis Temp Controls  
Mechanical Latches  
Electronic Locks  
Subminiature Door Openers  
Micro Clutches  
Spring loaded Releases

### **Automotive**

Environmental controls  
Door Locks  
Mirror Controls  
Remote release  
Gear changing Trigger  
Pneumatic Valve  
Alarms  
Motor Protectors

### **Medical**

Surgical Instruments  
Prosthetic Limbs  
Remote Latches  
Steerable Catheters  
Blood Pressure Test Valves  
Exoskeletal Assistance  
Vacumn Test Manipulators  
Micro Pumps

### **Miscellaneous**

Smart materials  
Robotic limbs  
Alarm Devices  
Light Fibre Switches  
Ultralight Remote Control  
Mechanical Scanners

## Frequently Asked Questions

### Question

How fast can muscle wire (nitinol) contract?

### Answer

One thousandth of a second

### Question

How fast can muscle wire contract and relax?

### Answer

Muscle wire can contract in one thousandth of a second, although a complete contract and relax action depends on a number of factors, mainly it depends on the conditions in which it cools, for example the quicker muscle wire is cooled, the faster a cycle time can be achieved.

### Question

How do I cool the muscle wire quicker and speed up the cycle time?

### Answer

The disbursement of the heat within the muscle wire is key to a quicker cooling rate. This can be achieved in a number of ways.

A fan (to circulate cold air around the muscle wire)

A heat sink (in contact with muscle wire to carry away the heat)

Rubber tubing (surround the muscle wire in a cool rubber tubing to disperse the heat)

In extreme situations water can also be used, although this method is not recommended, as more power is needed to contract muscle wire, which in turn increases the risk of damaging the wire through overheating and could even ignite small lengths of muscle wire.

### Question

What is the lifetime expectancy of muscle wire?

### Answer

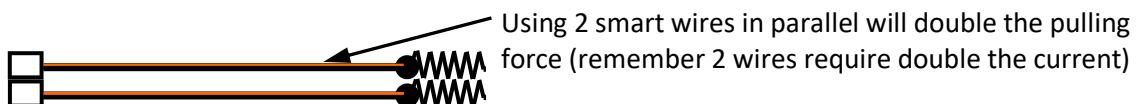
Muscle wire is capable of functioning for millions of cycles if used correctly.

### Question

Can the pulling force of smart wire be increased?

### Answer

Smart wires pulling force cannot be increased by supplying current beyond the wires specified limit, although two or more smart wires can be used together, which will increase the pulling force as shown below.



### Question

Can you increase the length in which smart wire moves when heated?

**Answer** Smart wire shortens 4%-5% of original length, this percentage is fixed, but by increasing the length of smart wire used, the distance moved is increased.

## Dancing Toy Product Assembly

### Polymorph

Polymorph is a material which belongs to the polycaprolactone group of polymers. This thermoplastic material has the ability to become soft and pliable when heated in hot water, this allows the material to be shaped and reshaped any number of times.



Polymorph is a smart polymer due to its ability to melt at low (skin safe) temperatures other strengths include very impact resistant, biodegradability and can generally be bonded together using most adhesives.

The ability to be moulded, shaped and reshaped any number of times, makes polymorph an ideal material for 3D modelling.

Polymorph is generally supplied as pellets / granules that resemble white beads as shown below. The following information has been designed to divide the assembly into small sub-assemblies. It is recommended that groups of students work on different sub-assemblies concurrently to speed up the manufacturing process.

When polymorph is immersed in boiling water, it becomes extremely hot and should be handled by a responsible individual or teacher. For this reason, it is recommended that the teacher heats and forms the polymorph into flat manageable pieces as shown in assembly task A (polymorph can also be heated by microwave at 10 second intervals until mouldable)

#### Making Task A: Moulding Polymorph

Polymorph granules are placed in a bowl and heated with boiling water, until granules slowly change from a white appearance to clear.

When all the polymorph granules are clear and fused together, carefully remove using tongs and mould together by hand.

#### STEP 1

Polymorph granules are poured into bowl and heated with boiling water until all granules change colour and fuse together.



## **Dancing Toy Product Assembly**

### **STEP 2**

The fused polymorph is removed and allowed to cool slightly before moulding together by hand, when moulding the polymorph becomes soft and pliable similar to a modelling clay.

Stretch the polymorph ready for rolling, if at any time polymorph becomes rigid or tough to mould submerge in boiling water to soften and make pliable.



### **STEP 3**

Using a rolling pin, roll polymorph out as shown until an approximate thickness of 5mm is achieved. If polymorph becomes difficult to roll or white in appearance submerge in boiling water until clear.

To achieve a smooth surface on both sides it is advised that during rolling, polymorph is turned over occasionally.



When a thickness of 5mm is achieved, allow polymorph to cool on a flat surface.

Roll polymorph flat ensuring no air bubbles or cracks are visible. If cracks or air bubbles are visible, submerge in boiling water and push air out and cracks together, polymorph will fuse together immediately.



### **STEP 4**

Once cool remove excess water with a hand towel and when fully dry, place template of chosen design on surface of polymorph as shown.



## Dancing Toy Product Assembly

### Making Task B: The Coping Saw

Coping saws are used to cut unusual shapes and curves. In a workshop fret saws are used, but due to polymorph's low melting temperature the heat generated by industrial tools makes them unsuitable for this material.

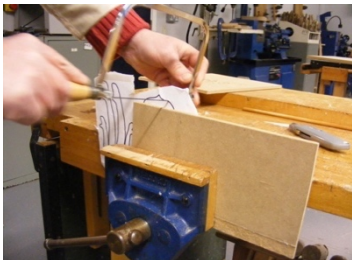
Also using a coping saw requires practice and skill as it is difficult to control around complex shapes.



By Clamping the flat polymorph between two pieces of wood in the vice, the movement of the material when cutting is reduced. Position the design outline below wood support where possible to prevent over cutting into image.

#### STEP 1

Carefully remove the excess material making sure design is safe between the two pieces of wood clamping the polymorph.



#### STEP 2

Using the coping saw move around perimeter (outside) of template, cutting approximately 3mm on the outside of line. If the repositioning of material is required remove coping saw by cutting away from design until blade is clear. Continue this process until all of the template is removed.

Repositioning of material without removing saw, could result in the blade being bent or broken.

## Dancing Toy Product Assembly

### Making Task C: The Chisel

When using chisels safety is of high priority, for this reasons chisels should be sharpened on a regular basis.

A blunt chisel tends to slip off the surface of the material, generally in the direction of a hand or a person, for this reason hands should always be placed behind the cutting edge and material securely fastened to bench using a G clamp or other clamping device.

The picture below shows a bevel edged chisel being used to shave the edge off a piece of polymorph, the bevel edged chisel is an ideal tool for this process as they are slightly undercut making them ideal to cut out small corners.

#### Remember

Securely fasten material to prevent movement.

Use a sharp chisel.



By Clamping the flat polymorph between two pieces of wood using a G clamp, the movement of the material when shaving is reduced.

#### STEP 1

Carefully shave away the excess material making sure design is securely clamped between the two pieces of wood to prevent movement.



#### STEP 2

Using the appropriate chisel move around perimeter (outside) of template, cutting directly on the outside of line.

The shaving process requires the material to be repositioned on several occasions.

Remember to securely clamp material after repositioning.

## Dancing Toy Product Assembly

### Drilling



STEP 3



STEP 4

#### STEP 3

Polymorph granules are poured into bowl and heated with boiling water until all granules change colour and fuse together. Roll the fused polymorph on a slightly wet wooden surface, until a short round bar shape is achieved.

Slightly submerge the back of clown's head in boiling water until back slightly changes colour and press newly formed bar shape into back of clown until fused together.

**For two parts of polymorph to fuse together, both parts need to be mouldable and soft to the touch.**

#### STEP 4

Securely fasten moulded clown between two pieces of wood and drill hole as shown, using a hand operated drill.



#### STEP 5

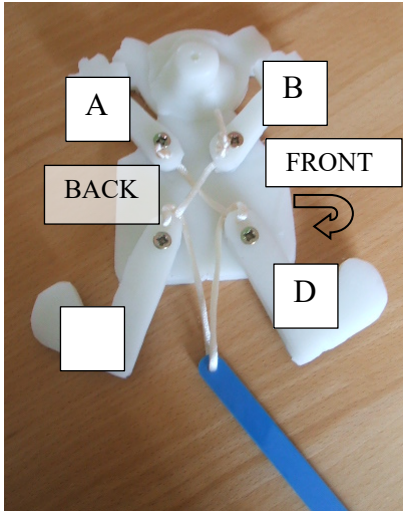
Remove template and replace with hand drawn clown.(or students own design)

#### STEP 6

Always clamp polymorph between two pieces of wood and securely fasten in vice when drilling.



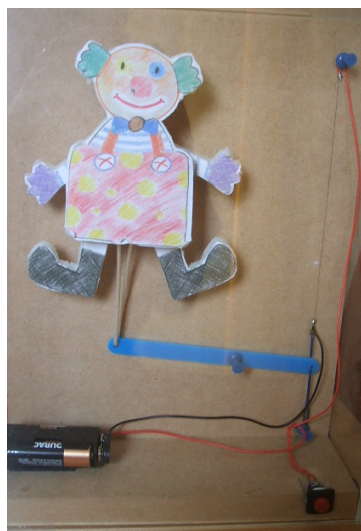
## Dancing Toy Product Assembly



The threading up of the limbs of the toy is easiest to explain by giving each limb a letter, see the photograph. Thread through A first from the back of the limb through to the front and pull the cord almost through to the end leaving enough to put a knot in when we have finished threading. Then through D from front to back then feed onto your lever from your mechanism. Thread through C from back to front then up to B from front to back and knot the end with a large enough knot to prevent it from coming back through the hole. Gradually feedback any excess cord back to A and knot the end.



Mould a piece of polymorph into a small fat sausage shape and dip the head of the cut out shape into warm water to heat a little. With the sausage shape hot and the head warm (allow it to slightly change colour) and then mould the end of the sausage shape down onto the back of the head. This provides you with a piece on the back of the head onto which you can place a screw through the wooden back ground to screw into your toy and securely fasten it down to the base board.



The finished product attached to the lever and threaded up. Then attached to the baseboard.



## Extension Activity CAD Drawing of clown (Computer Aided Design)

Computers can deal with work more efficiently, both in the designing of a product and in its production. They utilise both CAD (Computer aided design) and CAM (Computer aided manufacture) systems.

An example of a students hand drawn design as shown to the right. The student decided to redraw his design using a drawing software ready for manufacture.

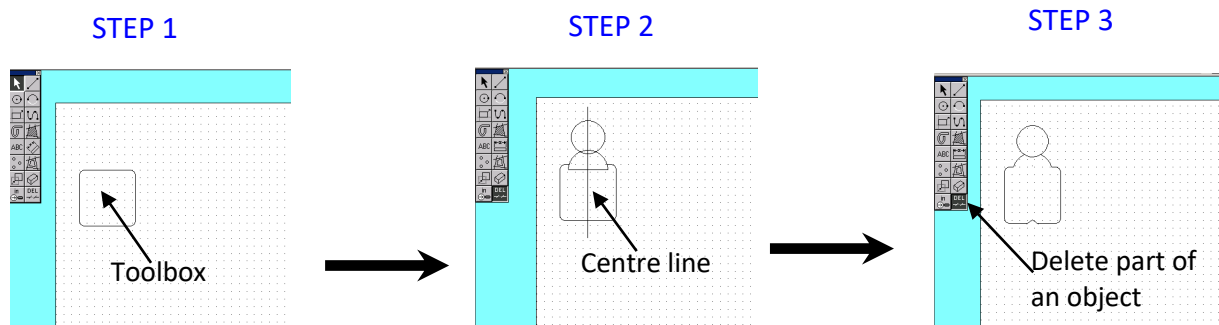
The student achieved a working prototype in small easy to manage steps, as shown on following pages.






### CLOWN BODY


By selecting the various tools from the tool box the student slowly assembled the main body of the clown, carefully using the centre line as a focal point.


Once the main body was assembled, the  (delete part of an object) was selected and the internal lines removed as shown in [STEP 3](#)




**STEP 1** With grid lock on select the shapes  tool located in toolbox on left of screen, draw rectangle with a vertical centre line.


**STEP 2** Using the circles tool  draw a circle, then select  left click to the side of circle and drag box around circle. Select Edit at top of screen and scroll down to copy, repeat the process and select paste an exact copy is produced below the original circle.

Using one of the circles, draw a horizontal line through the centre of circle, and  delete the appropriate lines until a half circle is produced.


To position drawings within main drawing Select  left click to side of drawing to be moved and drag box around drawing, select the box located in centre of highlighted drawing and drag into desired position.


**A half circle can also be produced using the arc located within toolbox.**


Draw a line the diameter of desired half circle and select Arc  in toolbox then select both ends of the line.

**STEP 3** Using delete part of an  object located in toolbox, delete the appropriate lines until body

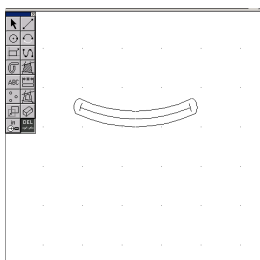
### FACIAL FEATURES OF CLOWN

The facial features of the clown are achieved in a series of small drawings, to achieve this select VIEW at top of screen and zoom to required percentage or alternatively use the located on right of screen 

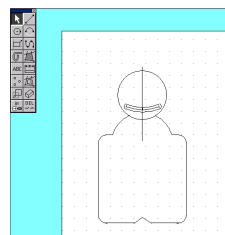
The student can draw the features in situ (in desired position) or to the side of main drawing and then drag into position using the select tool  to re-position and alter size of drawing.

To select drawing left click  and drag box around drawing to be resized or repositioned

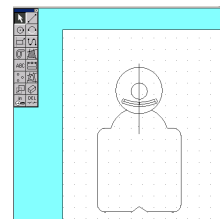
STEP 1



STEP 2




STEP 3

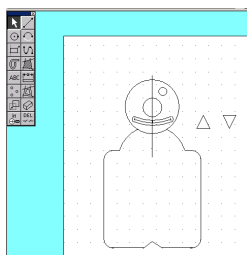


**STEP 1** The above mouth was achieved by drawing three circle slightly smaller than the previous one, then using two vertical lines the distance apart representing the width of clowns mouth.

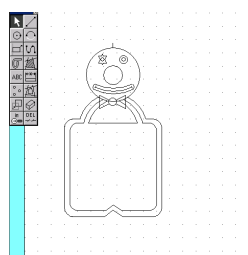
**STEP 2** Draw a vertical centre line and position mouth centrally on face.

**STEP 3** Using the circles tool  Draw a circle and position centrally for clowns nose.

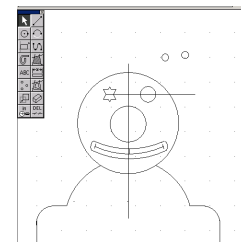
STEP 4




STEP 5




STEP 6



**STEP 4** Draw a circle and position as shown.

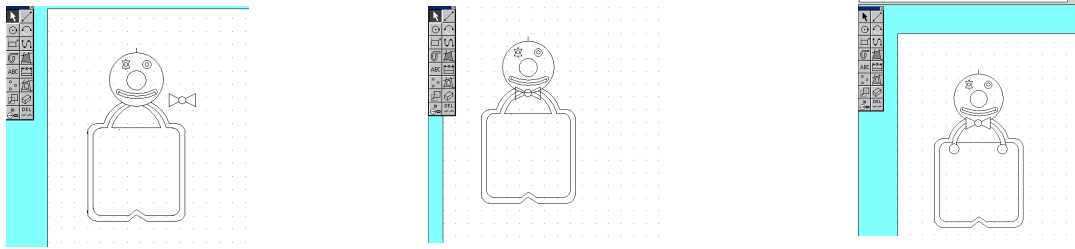
The left eye is a star, this is achieved by drawing a triangle then using the select tool  copy triangle and rotate 180



**STEP 5** Place one triangle directly on top of the other. Use the  tool to delete all internal lines.


**STEP 6** Draw a horizontal line and position star. Draw two small circles and position in centre of eyes (star and circle)


STEP 7

STEP 8

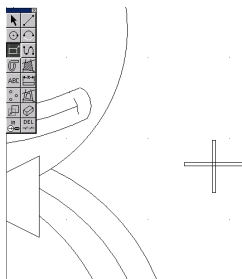


**STEP 7** Zoom picture  and using the line and circles  tool. Draw the bow tie to side of clown.

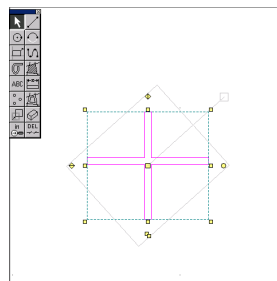
Using the line and arc tool draw internal lines. The drawing of the half circle was achieved by drawing a line the diameter of the desired half circle and selecting Arc  in the toolbox, then selecting both ends of the line.

**STEP 8** Using the select  tool click to the side of bow tie and drag box around drawing and release. Move cursor to centre box of highlighted bow tie and move into position shown.

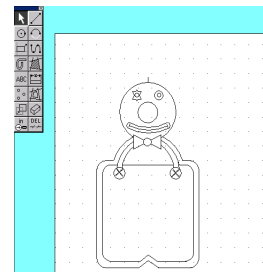
STEP 10






STEP 11



STEP 12

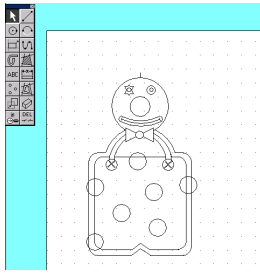


**STEP 10** Zoom  picture and using the  shapes tool, draw the cross to the side of clown.

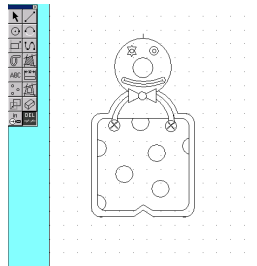
**STEP 11** Using the select  tool click to the side of cross and drag box around drawing and release. Move cursor to circle located centre right of highlighted cross and tilt into position shown.

**STEP 12** With cross still highlighted, select Edit, within scroll down menu select copy, repeat process and select paste. An exact highlighted copy is produced, holding button down left click the square located in centre of drawing and move to position shown.

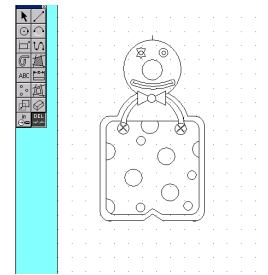
**STEP 13**





**STEP 14**




**STEP 15**

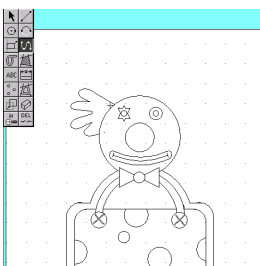


**STEP 13** Using the circles  tool place a number of circles as shown

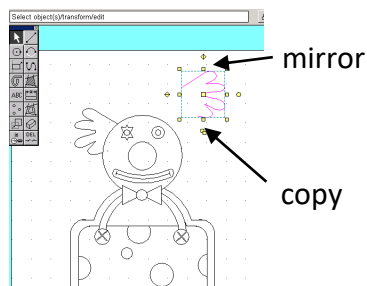
**STEP 14** using the delete  part of an object tool delete the appropriate lines

**STEP 15** Using the circles  tool place a number of small circles inside main body as shown

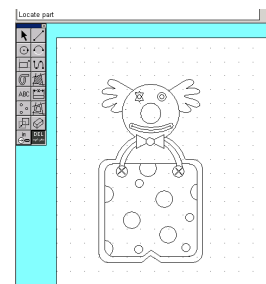
**STEP 16**






**STEP 17**



**STEP 18**

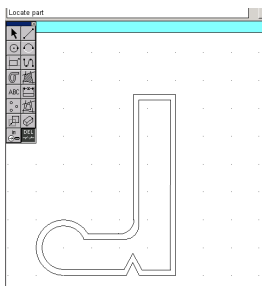


**STEP 16** Using the path  tool draw the clowns hair.

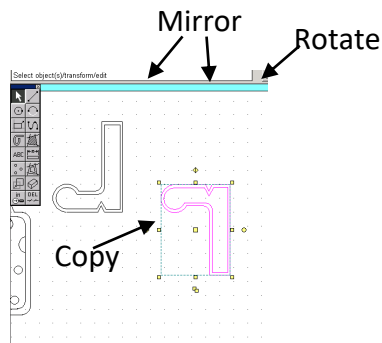
**STEP 17** select the clown hair  copy picture using  located bottom middle of highlighted drawing. Mirror the copied drawing by selecting  located top middle of highlighted drawing.

**STEP 18** Move highlighted drawing into position shown.

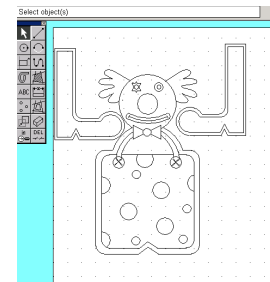
STEP 1






STEP 2




STEP 3

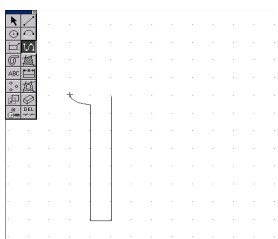


STEP 1 Using the skills learnt draw the boot as shown

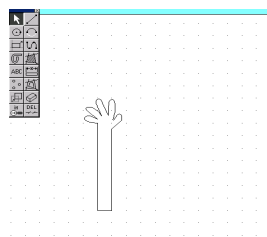
STEP 2 select the clown boot  copy picture using  located bottom middle of highlighted drawing. Mirror the copied drawing by selecting  located top middle of highlighted drawing.

To rotate drawing clock-wise or anti clock wise, use  located middle/ right of highlighted drawing.

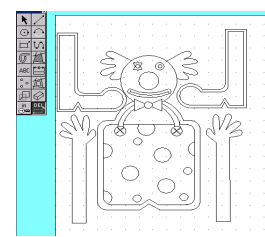
STEP 4






STEP 5






STEP 6

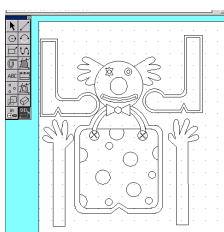


STEP 4 using the line  tool draw the arm as shown

STEP 5 select the attach  tool and path  tool and move cursor to where hand is to be drawn and left click mouse (line will be drawn attached). To draw the hand we must first de-select the attach tool. The hand is drawn by plotting a path, this is achieved by left clicking mouse over the area line is to be located

STEP 6 Select  drag box around drawing and copy and mirror using the copy  and mirror  tools located on highlighted drawing. Using the centrally located square position drawings as shown.

STEP 7



STEP 8

Draw two holes in each arms and legs

## Book 4 Teacher Resources

### Smart Materials Polymorph & Muscle wire



Using the CAD drawings, I selected parts of my design and cut different parts out of different coloured acrylics to make a mosaic effect.



### Acknowledgements

Gilbertson. Roger. G. 2000. *Muscle Wires Project Book. A hands-on guide to amazing robotic muscles that shorten when electrically powered.* San Rafael, CA: Mondo-tronics, Inc. 2000

<http://www.flying-pig.co.uk>

<http://www.cabaret.co.uk>

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