Contents

The Magic Manual

Section 3

Symmetry

A guide for fabricators and users to stations from the Magic Mathworks Travelling Circus

3. SYMMETRY

3.1 and **3.2** introduce mirror (**axial/reflexive**) and **rotation** symmetry respectively.
3.3 introduces **point (central)** symmetry as a distinct concept, because of its significance in 3 dimensions.
3.4 uses 1, 2 and 3 plane mirrors to review **3.1**, **3.2** and **3.3** respectively.
3.5 investigates **order of symmetry**, a group concept describing the overall symmetry of a body.

3.6 and **3.7** make demands on one's understanding of **3.1** and **3.2** through dissection puzzles in 2 and 3 dimensions respectively.
3.8 offers an opportunity to display one's knowledge by creating symmetrical designs.

3.9 shows how physical laws can produce symmetrical objects.

3.1.1 MIRROR SYMMETRY

c The same.

p The concept is presented - through a counterexample - and extended: the experimenter discovers that any number of symmetry axes is possible.

3.1.2 THE INFINITE KEYBOARD

c There are $360/\theta$ repetitions of a motif in 2 mirrors inclined at θ degrees:
if $\theta = 0$, the number is limited only by physical constraints like attenuation.

p The investigators enjoy this limiting case of the kaleidoscope, introduced in **3.1.1**.

3.1.3 THE MAGIC MIRROR CUBE

c A mirror cube imposes 3 perpendicular planes of symmetry on the final image.

p Accordingly, the visitors are challenged to select from a variety of shapes the 1/8 which, correctly orientated, will produce on reflection the whole solid illustrated.

3.2 ROTATION SYMMETRY 1, 2 & 3

c The same.

p **3.2.1.1** & **2** teach the concept: **3.2.1.1** provides an example of what the experimenter can produce with **3.2.1.2**.
3.2.2 tests the experimenter's understanding by requiring him/her to complete a design with such symmetry.

3.3 POINT SYMMETRY

c The same.

p The visitor manipulates a playing card and a calcite crystal to show that point symmetry and 1/2-turn symmetry (rotation symmetry order 2) are one and the same in 2 dimensions but not in 3.

3.4 YOU AND YOUR REFLECTION

c Begin with a plane mirror, add a 2nd and a 3rd at right angles and you demonstrate reflection in a plane, a line and a point respectively. Correspondingly, combination of the original motif and its reflection forms objects with mirror, 1/2-turn and point symmetry.

p The experimenter's face provides the motif.

3.5 ORDER OF SYMMETRY

c The same.

p The order of symmetry is a number. This number corresponds to the number of ways an object fits the object-shaped hole.

3.6-7 SYMMETRICAL PUZZLES

c The number of elements of a given shape limits the possible symmetries of the overall design.

p By applying that principle one can tackle these puzzles systematically.

3.6 2-D PUZZLES 1-7

3.6.1-6 all involve dissecting one shape or set of shapes into another. The suffices **A** and **B** denote design variants.

A concept irrelevant to the present topic but implicit throughout is **conservation of area**. Where only 1 figure is involved, i.e. k units produce 1 replica, advanced students can infer that that the replica is scaled $\sqrt{k}$. Examples: **3.6.4**, **3.6.6**.

3.6.1 **The Shapes Tree**: isosceles triangle 1 - isosceles triangle 2 - rectangle - kite - parallelogram 1 - parallelogram 2

3.6.2 A,B **Square - Octagon** Arrangement **B** builds in a clue and is intended therefore to be the easier option.

3.6.3 **Square - Greek Cross**

3.6.4 A **3 Hexagons - 1 Hexagon**
B **3 Hexagons - 1 Hexagon - 1 Rhombus** (not illustrated)

Arrangement **A** builds in a clue and is intended therefore to be the easier option. The rhombus in **B** allows a number of variants, based on the fact that a pair of equilateral triangles (blue) and isosceles (red) form the same rhombus.

3.6.5 A **2 Greek Crosses - 1 Square**
B **4 Squares - 2 Greek Crosses - 1 Square**

The 8 congruent elements of **B** allow the large square to be assembled directly from the 4 small or the less obvious solution forced in the case of **A**.

3.6.6 **3 Hexagrams - 1 Hexagram**

3.6.7 **The Oblongless Oblong**

3.7 3-D PUZZLES 1-6

In most cases the reason why 3-D dissection puzzles *are* puzzles is that they require the puzzler to look down symmetry axes not obvious from the external shape: for example, in case **3.7.1**, the 2-axis of the tetrahedron; in cases **3.7.3-5**, the 3-axis of the cube. It is instructive to cut an expanded polystyrene cube with an electric fretsaw to produce the 2 elements of **3.7.3**. **3.7.6** is the first stellation of the rhombic dodecahedron, **3.7.5** a cube: but 3-axes are key to the solution of both puzzles. **3.7.4.** presents a further complication: the 8 constituent cubes belong to 2 chiral sets. (It is interesting to find a systematic proceedure for moving from 1 of the 4 solutions into another.) An instructive extension activity in cases **3.7.1-3** is to construct the elements from the interlocking polygonal tiles of a construction kit: Polydron's 'Frameworks' are particularly suitable. Note that in puzzles **3.7.1-3** and **3.7.6** *all* the elements are congruent.

3.7.1 **The 2-Piece Tetrahedron**

3.7.2 **The 4-Piece Tetrahedron**

3.7.3 **The 2-Piece Cube**

3.7.4 **The 4-Colour Cubes**

3.7.5 **The Antipodean Cube**

3.7.6 **The Rhombic Star**

3.8 TILES IN CUTOUTS

c The interior angles of all the polygons used here are multiples of 30^{o}.
This makes many alternative dissections possible.
The requirement here is for symmetrical ones.

p One must recognise a grouping in order to repeat it and thus achieve symmetry.

3.9.1 SOAP FILMS

c Soap films satisfy these conditions:

1. The total surface area is minimal for the boundary spanned.
2. All surfaces meet in a dihedral angle of 120^{o}.
3. All edges meet at an angle of arccos -1/3.

p According to their level, visitors can:

* recognise, describe and, if possible, name shapes;
* identify symmetries;
* vary the boundaries spanned and try to determine which quantities are invariant.

3.9.2 MOTORWAY NETWORKS

c If the above 'property 1' holds, a soap band of constant width will have minimal length.

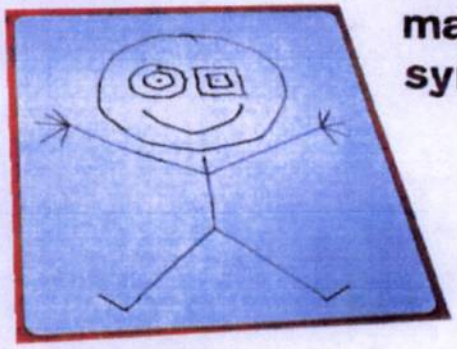
p This is achieved by confining the film between parallel plates. We conduct an analogue experiment: we minimise the total length of a motorway network (the soap band) required to connect a number of cities (pins normal to the plates).

SECTION		AGE RANGE					
SYMMETRY		Appropriate point of entry - not necessarily to the task set by the caption - and levels on which extension activities generated (some to be pursued off-site)					
STATION							
NUMBER	NAME	4	7	10	13	16	19+
3.1.1	MIRROR SYMMETRY	*	*	*		*	
3.1.2	THE INFINITE KEYBOARD		*	*	*		
3.1.3	THE MAGIC MIRROR CUBE			*	*		
3.2.1.1	ROTATION SYMMETRY 1		*	*	*		
3.2.1.2	ROTATION SYMMETRY 2		*	*	*		
3.2.2	ROTATION SYMMETRY 3			*	*		
3.3	POINT SYMMETRY				*	*	
3.4	YOU AND YOUR REFLECTION			*	*	*	
3.5	ORDER OF SYMMETRY				*	*	*
3.6.1	SYMMETRICAL PUZZLES (2-D) 1		*	*	*		
3.6.2	SYMMETRICAL PUZZLES (2-D) 2		*	*	*		
3.6.3	SYMMETRICAL PUZZLES (2-D) 3		*	*	*		
3.6.4	SYMMETRICAL PUZZLES (2-D) 4		*	*	*		
3.6.5	SYMMETRICAL PUZZLES (2-D) 5		*	*	*		
3.6.6	SYMMETRICAL PUZZLES (2-D) 6		*	*	*		
3.6.7	SYMMETRICAL PUZZLES (2-D) 7			*	*		
3.7.1	SYMMETRICAL PUZZLES (3-D) 1			*	*		
3.7.2	SYMMETRICAL PUZZLES (3-D) 2			*	*		
3.7.3	SYMMETRICAL PUZZLES (3-D) 3			*	*		
3.7.4	SYMMETRICAL PUZZLES (3-D) 4			*	*	*	
3.7.5	SYMMETRICAL PUZZLES (3-D) 5			*	*	*	
3.7.6	SYMMETRICAL PUZZLES (3-D) 6			*	*	*	
3.8	TILES IN CUTOUTS	*	*	*	*		
3.9.1	SOAP FILMS	*	*	*	*	*	*
3.9.2	MOTORWAY NETWORKS			*	*	*	*

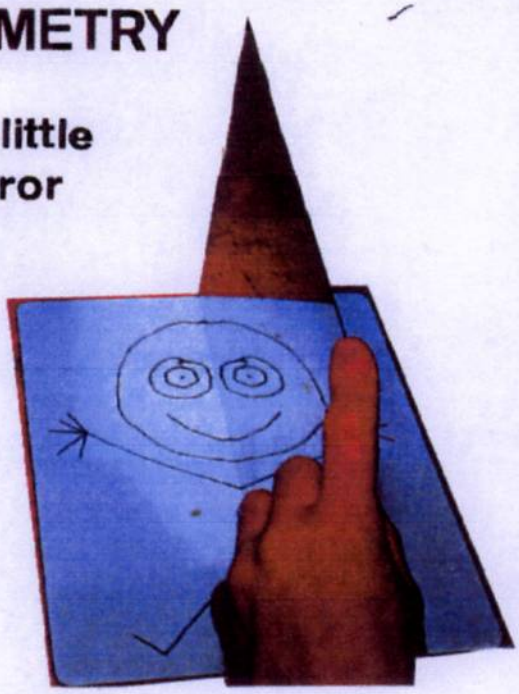
	INSTRUCTION NEEDED				SUPERVISION NEEDED			SERVICING NEEDED		
→	Needs no explan-ation or caption	Caption enough for most people	Needs aural prompt	Visitors must be talked through stages	None	Benefits from a helper's input	Session must be directed	None	A little	Much
3.1.1		*			*			*		
3.1.2		*			*			*		
3.1.3			*			*		*		
3.2.1.1	*				*			*		
3.2.1.2		*			*				*	
3.2.2		*			*			*		
3.3		*			*			*		
3.4			*		*			*		
3.5			*			*		*		
3.6.1			*		*			*		
3.6.2	*				*			*		
3.6.3	*				*			*		
3.6.4	*					*		*		
3.6.5			*			*		*		
3.6.6	*					*		*		
3.6.7		*			*			*		
3.7.1			*			*		*		
3.7.2		*				*		*		
3.7.3		*			*			*		
3.7.4		*				*		*		
3.7.5		*			*			*		
3.7.6		*				*		*		
3.8	*				*			*		
3.9.1			*			*			*	
3.9.2			*			*			*	

	NUMBER	TITLE
GROUP	3	SYMMETRY
STATION	3.1.1	MIRROR SYMMETRY
TOPIC		Mirror symmetry

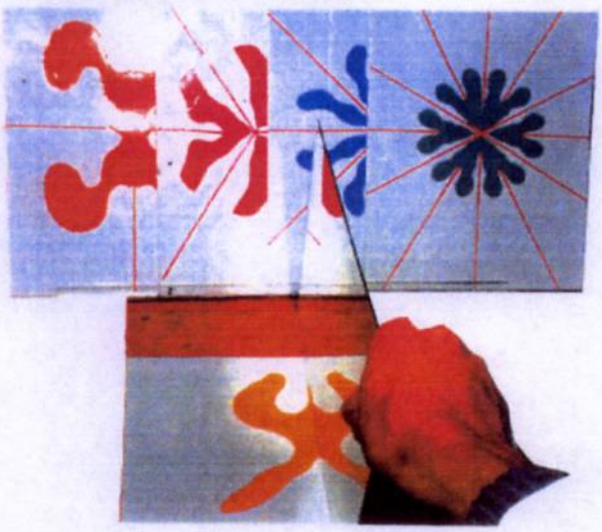
MIRROR SYMMETRY



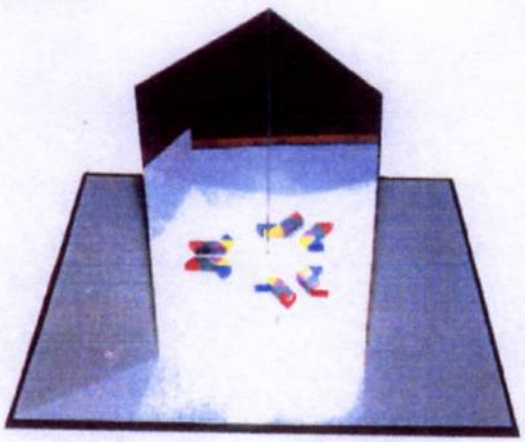
■ **Does the little man have mirror symmetry ?**

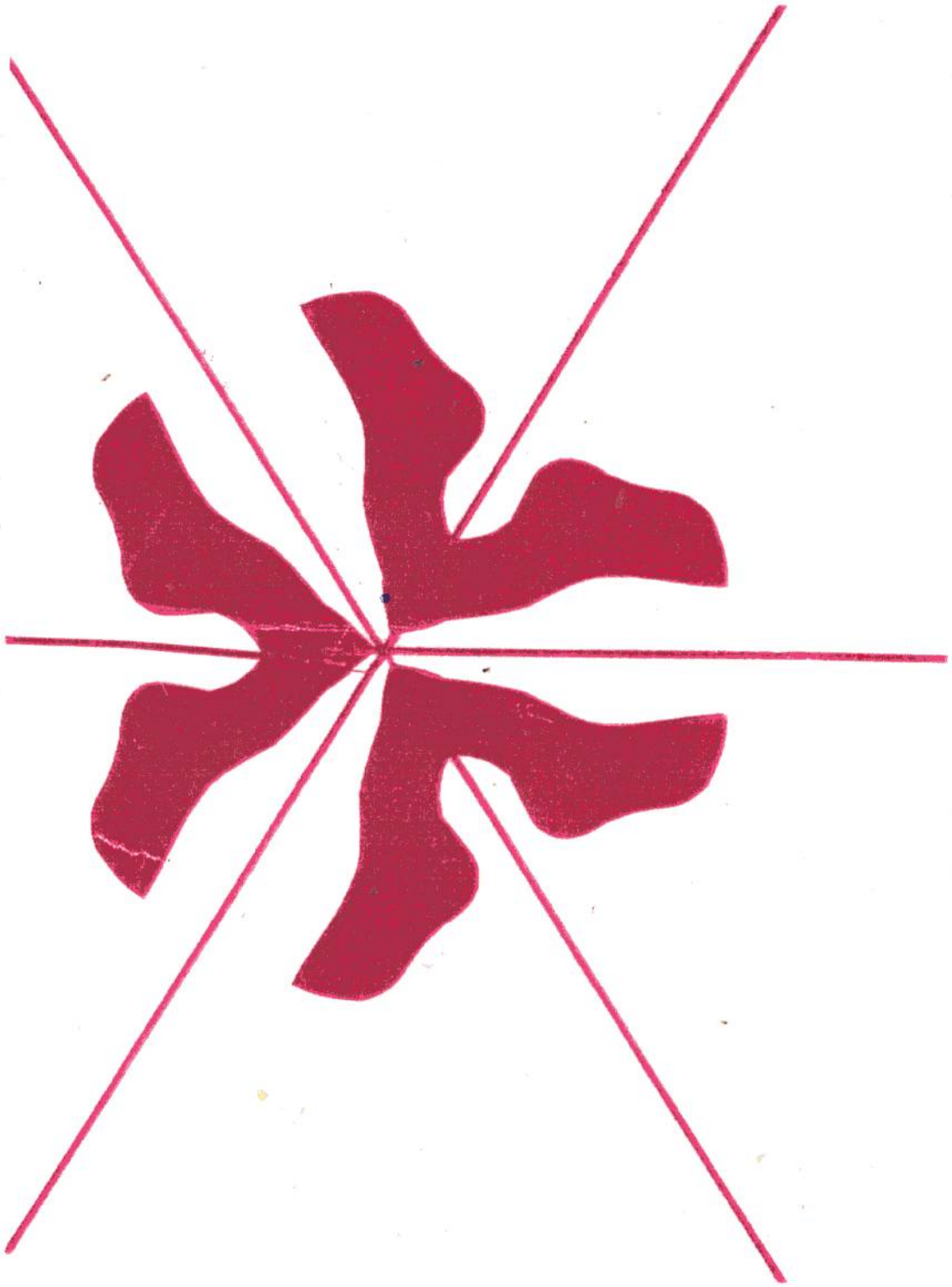


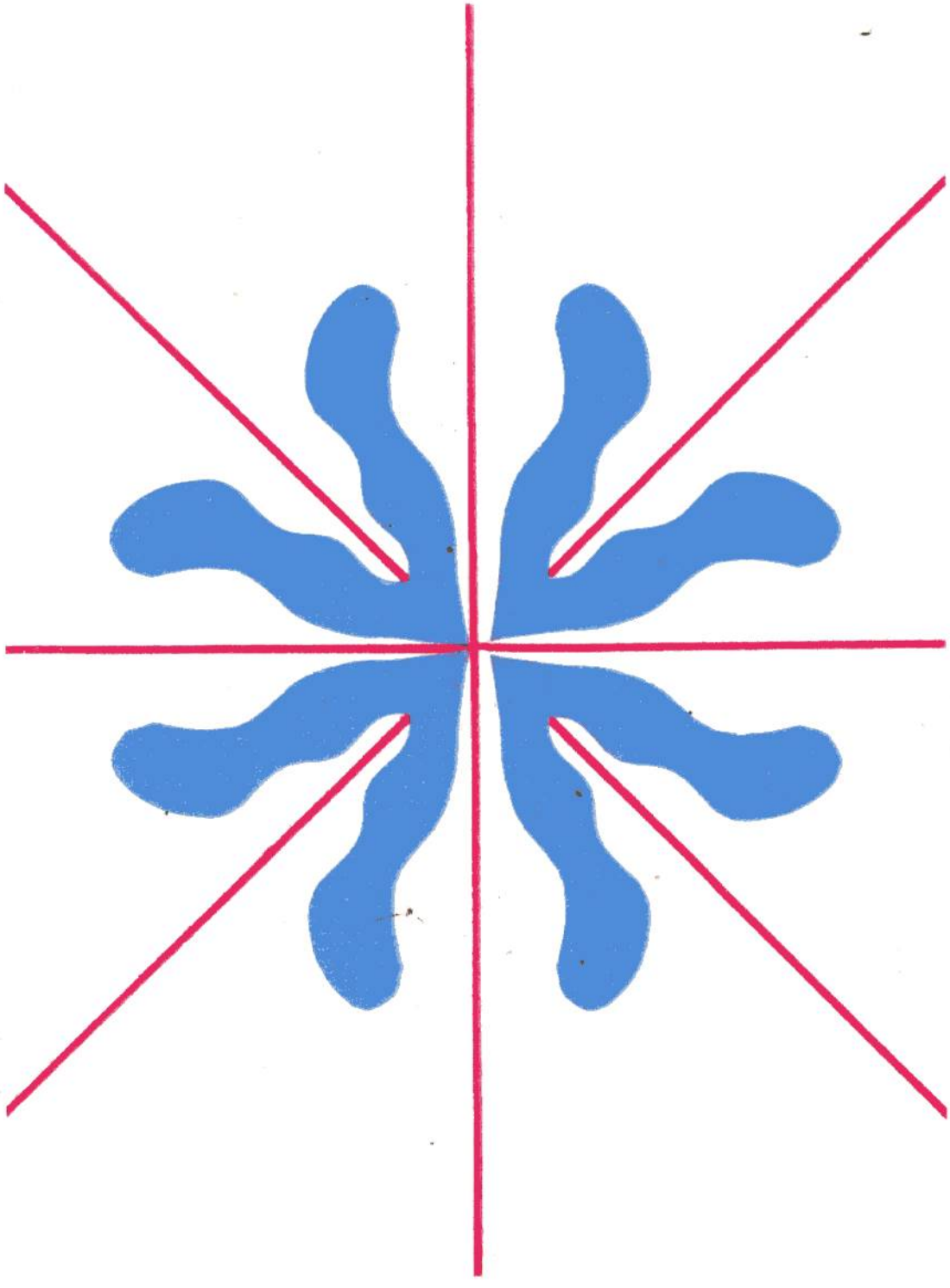
● **Check the mirror lines on these cutouts :**

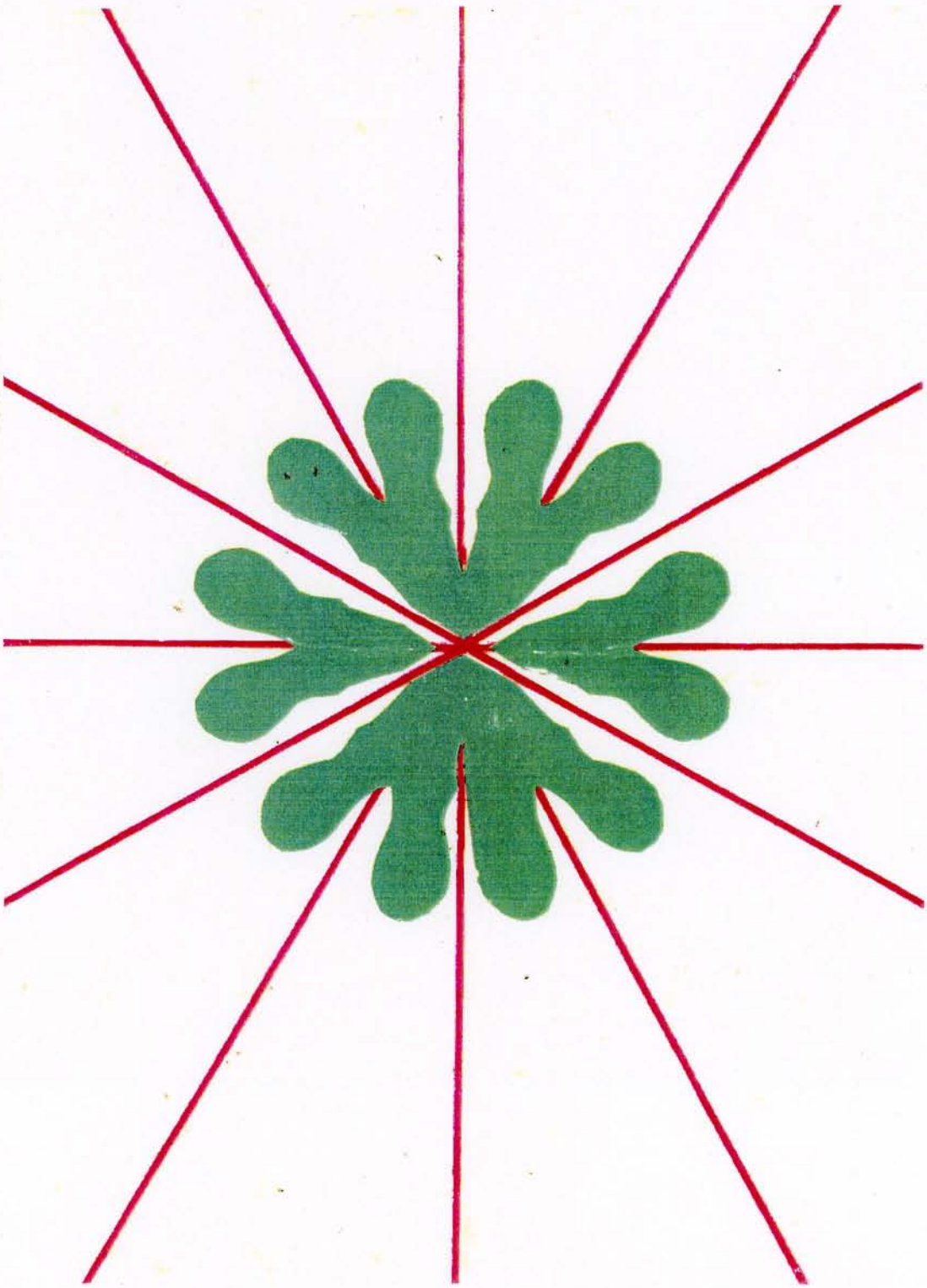


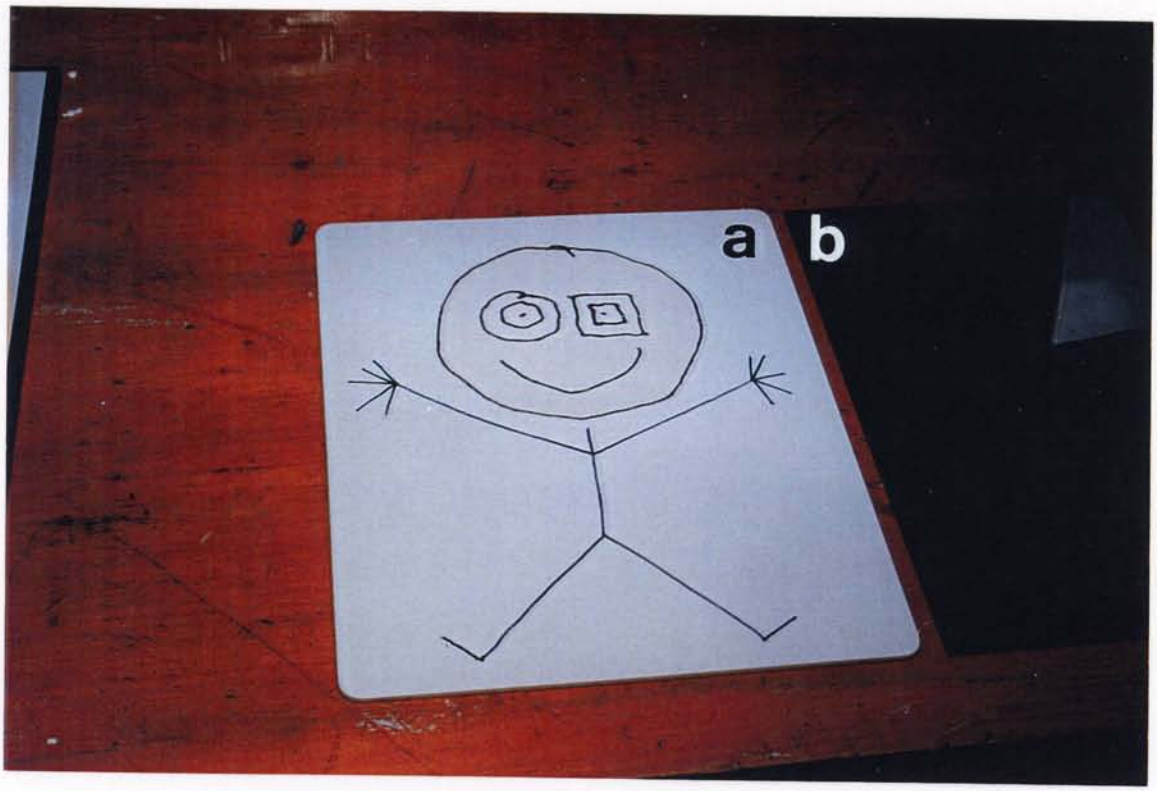
● **Make a design with 1,2,3,4,5,6 ... mirror lines :**

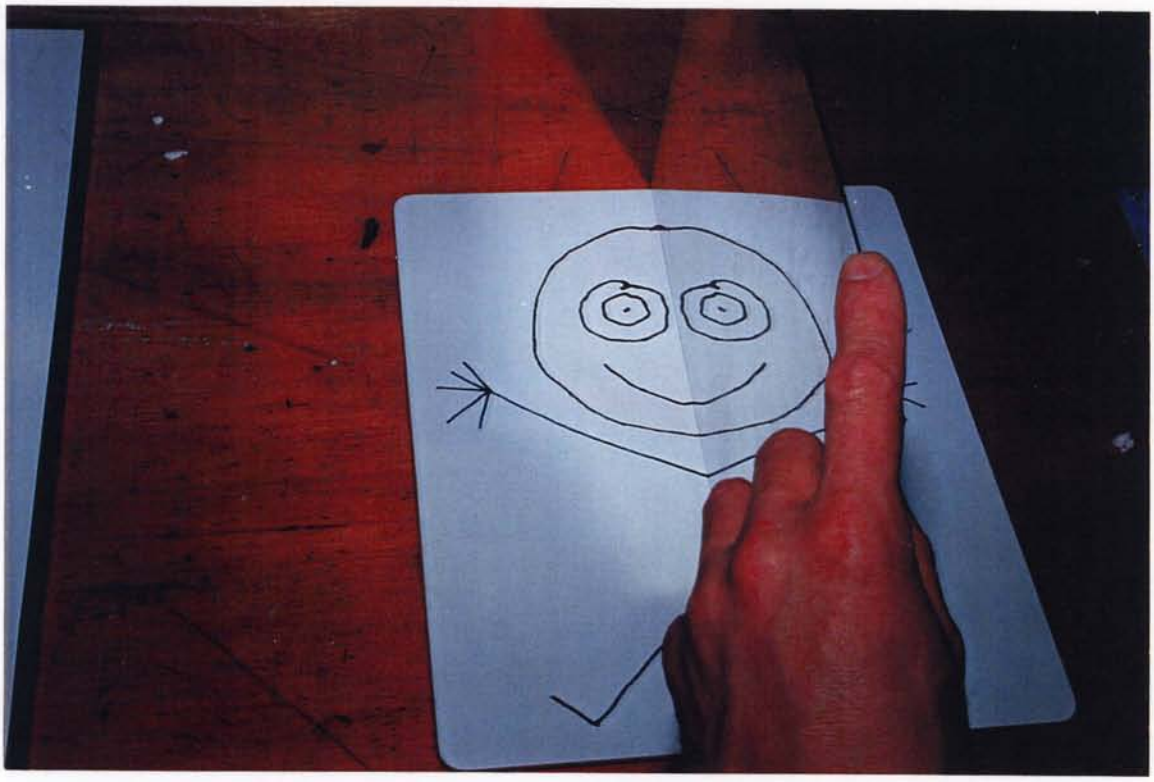


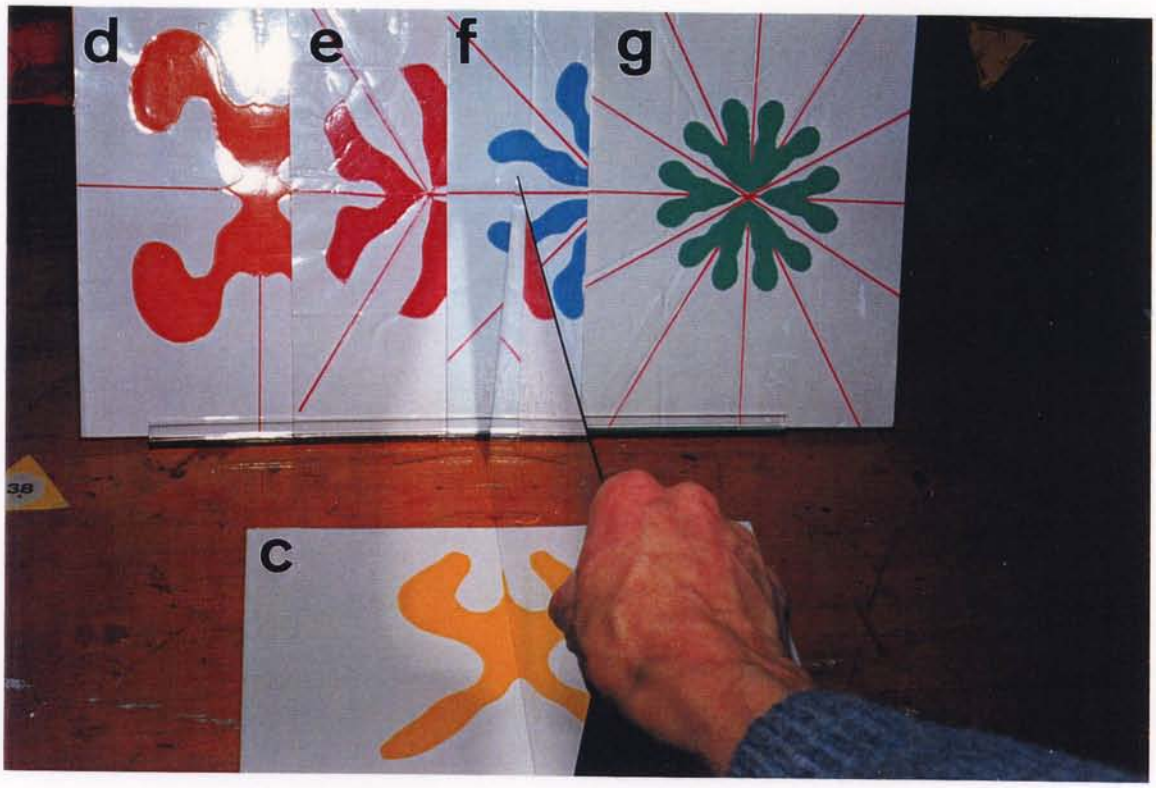


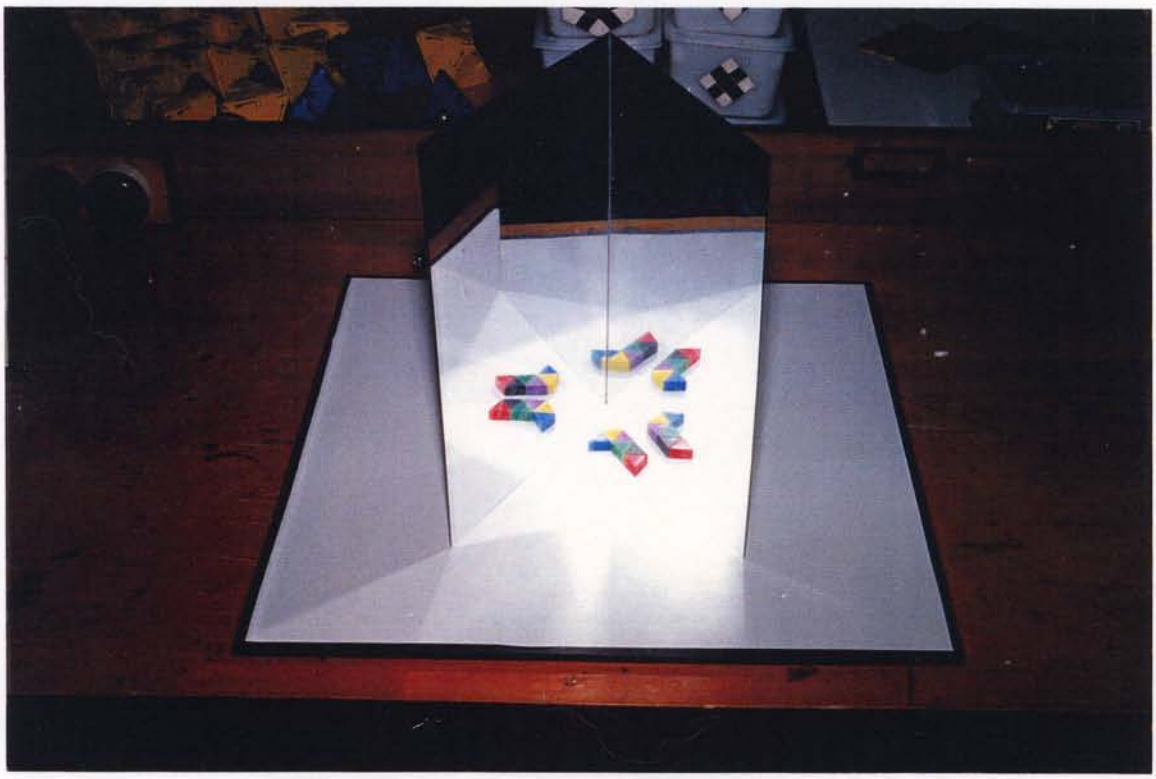


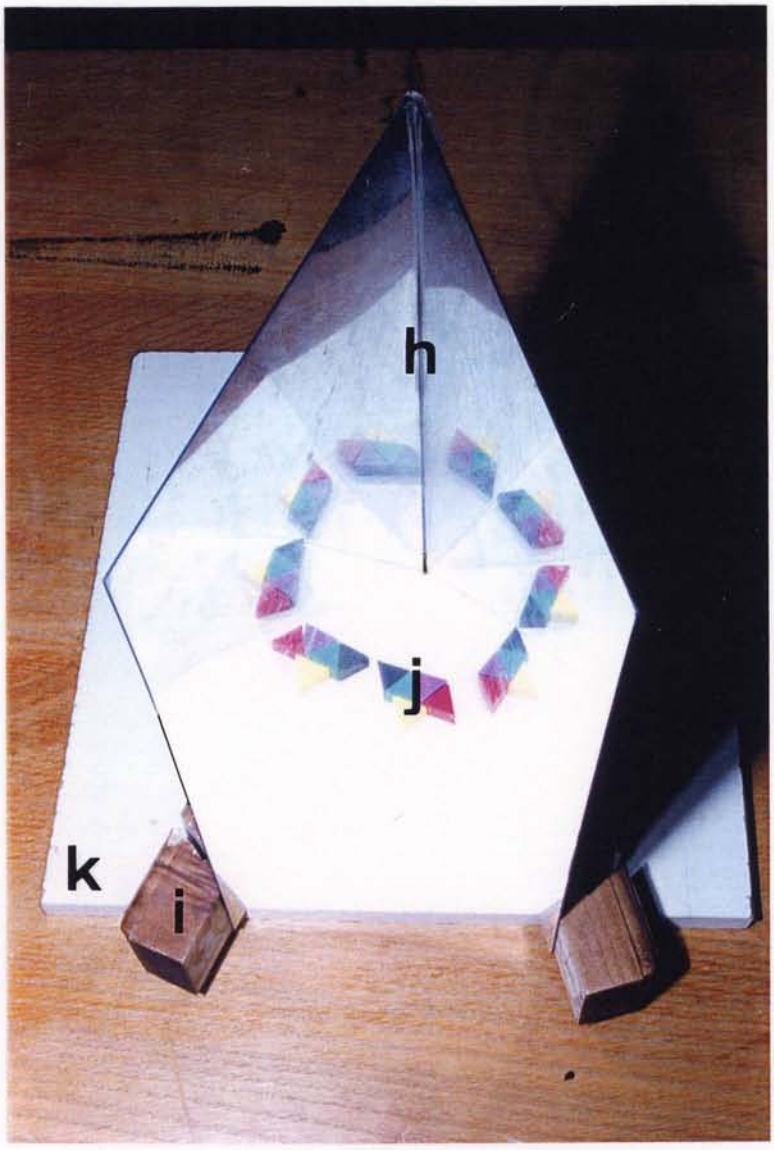


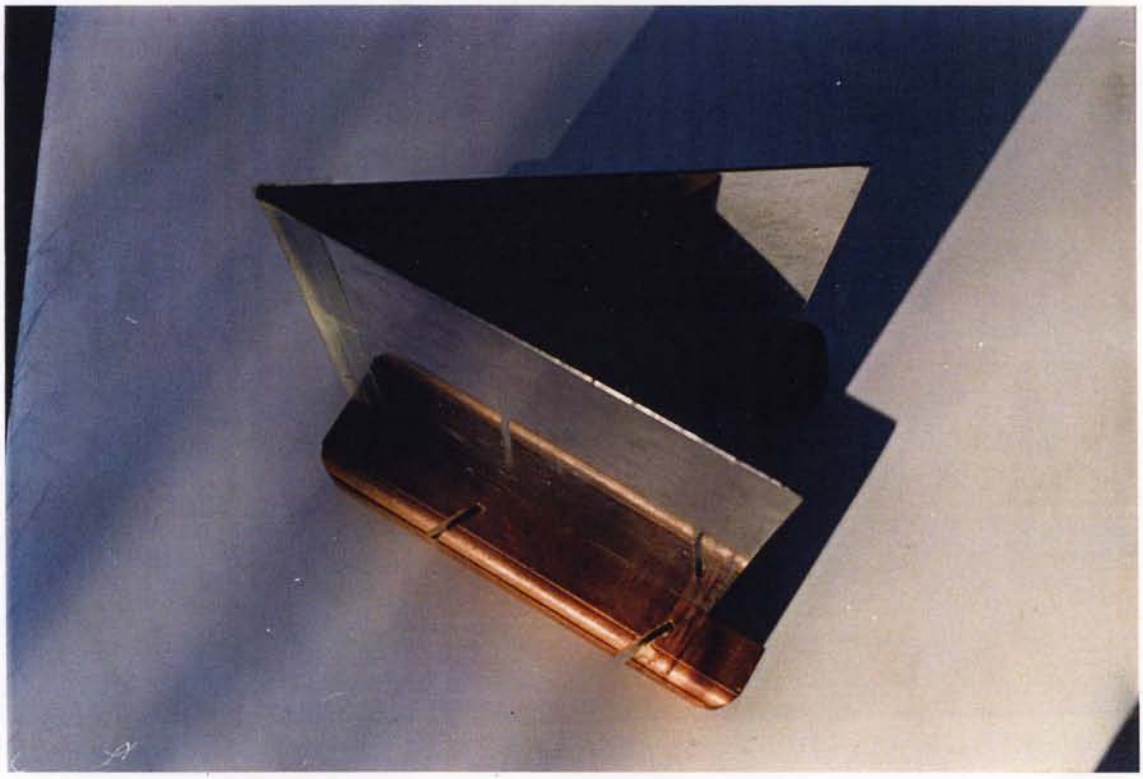

a
b




d
e
f
g
c




h
j
k
i

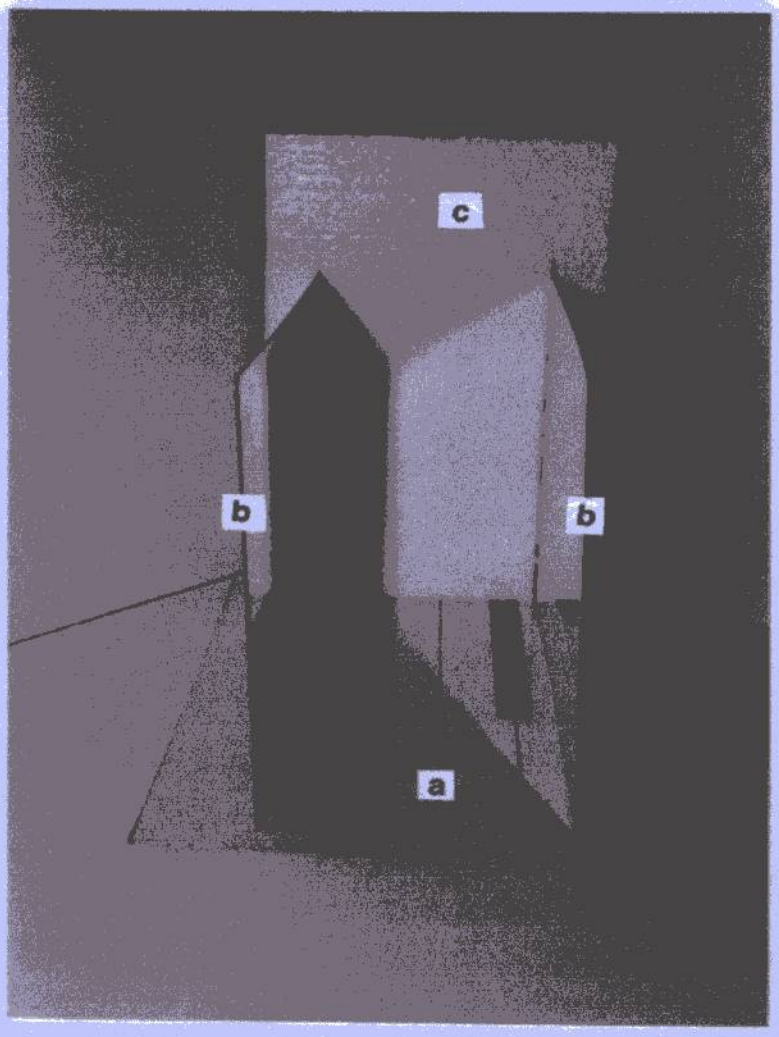


PICTURE KEY	DESCRIPTION	TRADE NAME	U.K. SOURCE
a	caption board as described, with asymmetric drawing, e.g. that shown		
b	mirror, A4 size	Economatics catalogue: 08803	Economatics Ltd (address above)
c - g	symmetrical cut-outs obtained by folding coloured paper appropriate -ly and cutting through the multiplied layers with scissors, mounted on caption boards as described, marked with symmetry axes as shown and covered with Transpaseal; design — number of axes **c** — 1 **d** — 2 **e** — 3 **f** — 4 **g** — 6		
h **i**	kaleidoscope, formed from 2 mirrors **b** hinged with tape, weighted with wood blocks. (These dissuade the experimenter from leaving the kaleidoscope flat on the table, which obscures its mode of use. They also act as handles.)		
j	any elements from which an interesting motif can be composed, e.g. the coloured prisms shown here	Prismo NES Arnold catalogue: NB 3649/8	NES Arnold Ltd (address above)
k	base: 2 sheets of white hardboard stuck back-to-back/white-faced Contiboard /..., 500 mm square		local
	(For older students a sheet of polar graph paper with radii at 15° intervals should be stuck to the base and covered with Transpaseal.)		Tarquin Publications (address above)
	c - g may also be set under the kaleidoscope.		

	NUMBER	TITLE
GROUP	3	SYMMETRY
STATION	3.1.2	THE INFINITE KEYBOARD
TOPIC		Mirror symmetry

(caption on apparatus itself:
see next page)


PLAY THE WORLD'S SMALLEST FULL-SIZE PIANO
only one hand needed more provided free

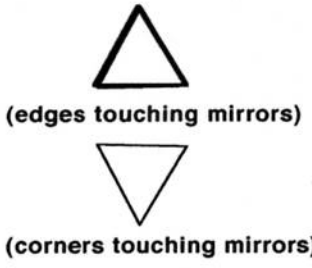

c
b
b
a

PICTURE KEY	DESCRIPTION	TRADE NAME	U.K. SOURCE
a	representation at scale of the standard keyboard between G# and D, the artwork laminated for protection		local
b	2 mirrors, A4 size, in 'landscape' orientation, located along the midlines of G# and D and slotted into **c**	Economatics catalogue: 08803	Economatics Ltd (address above)
c	backboard, A4 size, in 'portrait' orientation; 2 versions illustrated: - a caption board, - a slab of expanded polystyrene. To save weight, if a thick board is used, it should be in a light material.		local

	NUMBER	TITLE
GROUP	3	SYMMETRY
STATION	3.1.3	THE MAGIC MIRROR-CUBE
TOPIC		Mirror symmetry

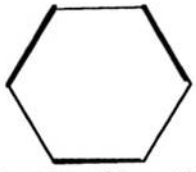
THE MAGIC MIRROR-CUBE

- **Lay a 2-D shape across the corner of the mirror-cube and a 3-D shape will appear:**



(edges touching mirrors)

(corners touching mirrors)

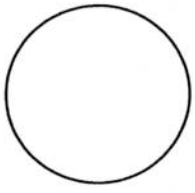


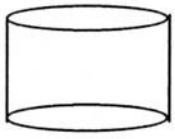
(3 edges touching mirrors)

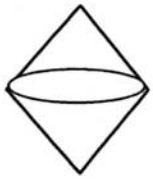
(2 edges,1 corner touching mirrors)

- **Use Polydron to build what you see.**
- **Use the curved pieces to make:**

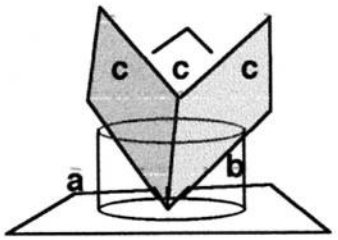
a sphere: a cylinder: a double cone:

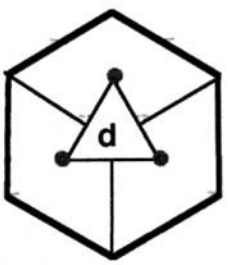


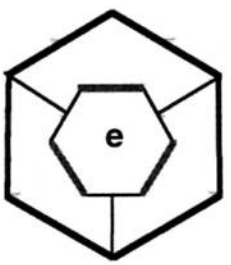


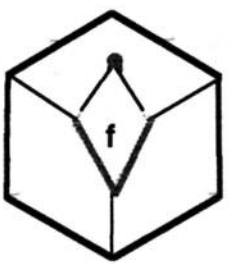


- **Use Polydron to build what you see.**









virtual solid appearing:	octahedron	cuboctahedron	truncated octahedron	rhombic dodecahedron
pieces needed for real solid:	triangles: 8	triangles: 8 squares: 6	hexagons: 8 squares: 6	rhombuses: 12

virtual solid:	sphere	cylinder	double cone
pieces of this kind needed for real solid:	8	4	8

PICTURE KEY	DESCRIPTION	TRADE NAME	U.K. SOURCE
a	whiteboard, 500 mm x 400 mm, used as tray; in this go the individual pieces **d - i**. To avoid confusion, it's best that, to complete the real solids, the modellers take pieces from a stock box to hand.		local
b	cylindrical trough, e.g. cake tin, 150 mm diam., to support mirror-cube as follows:		local
c	3 mirror pieces, 100 mm square, taped together along edges, cut from mirricard issued in A4 sheets	Economatics catalogue: 08803	Economatics Ltd (address above)
d - i	interlocking polygonal tiles	Polydron, cat. nos. as follows	Polydron International Ltd (address above)
d		Equilateral Triangle: 10-0300	
e		Hexagon: 10-0600	
f	diagonals in ratio $\sqrt{2}$:1	Rhombus: 10-0404	
g		1/8 Sphere: SP-1001	
h		1/4 Cylinder: SP-1004	
	This may be completed with the:	Quadrant: SP-1002	
i		1/4 Cone: SP-1003	

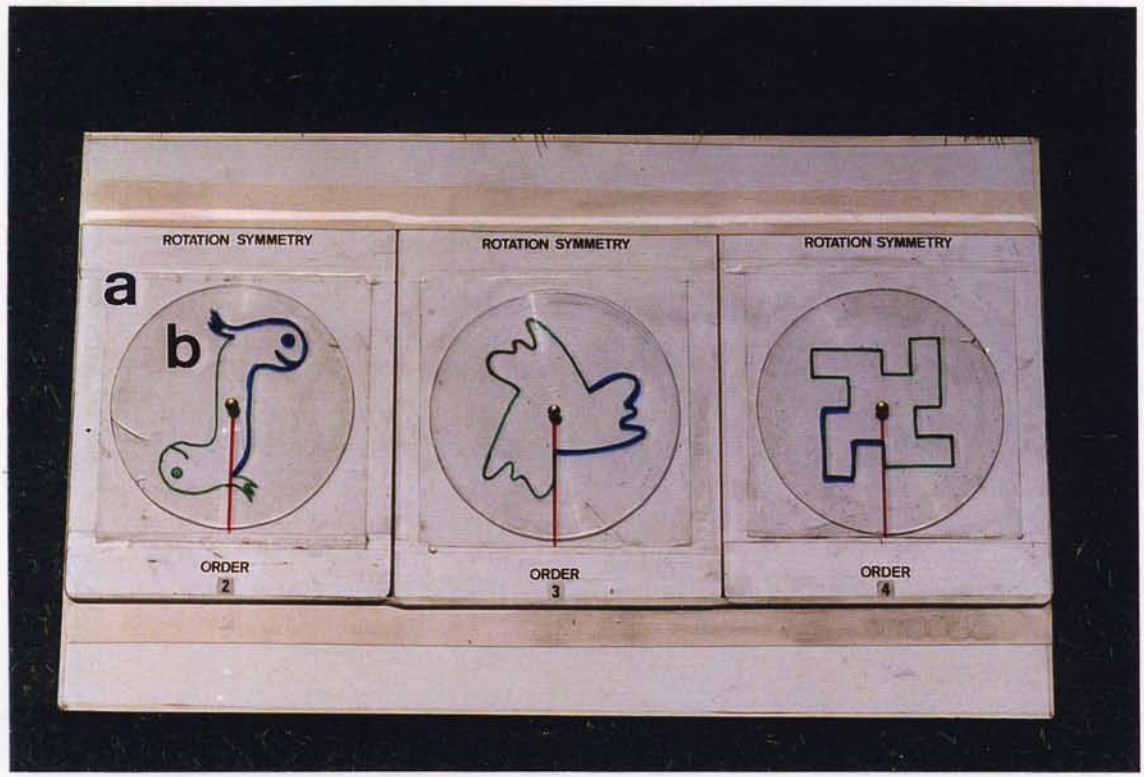
	NUMBER	TITLE
GROUP	3	SYMMETRY
STATION	3.2.1.1	ROTATION SYMMETRY 1
TOPIC		Rotation symmetry

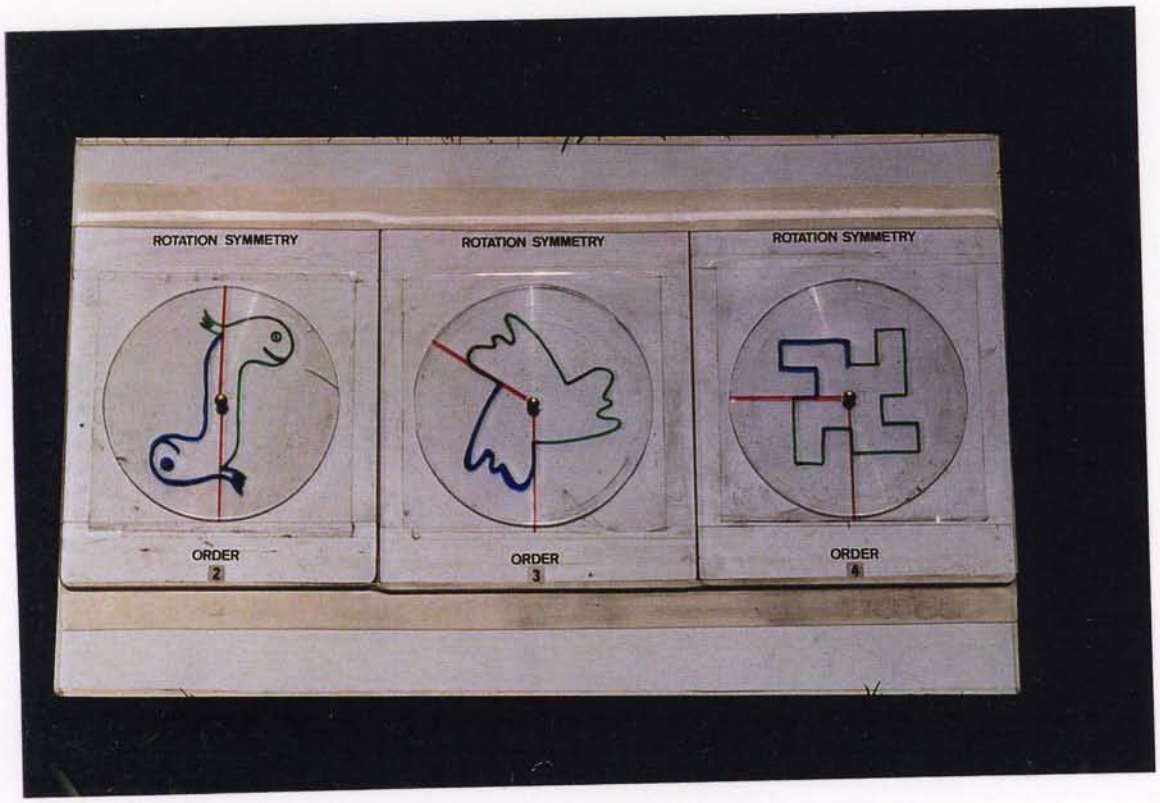
ROTATION SYMMETRY

- Turn each wheel once.

- Count how many times the blue picture fits the green one.

▶ This is the ORDER OF ROTATION SYMMETRY for each design.


a
b
ROTATION SYMMETRY
ORDER
2
ROTATION SYMMETRY
ORDER
3
ROTATION SYMMETRY
ORDER
4


ROTATION SYMMETRY
ORDER
2
ROTATION SYMMETRY
ORDER
3
ROTATION SYMMETRY
ORDER
4

PICTURE KEY	DESCRIPTION	TRADE NAME	U.K. SOURCE
a	caption boards as described, (here mounted on white-faced hardboard), carrying green drawings in permanent felt-tip		
b	Glodex disks, 100 mm radius, carrying blue drawings in permanent felt-tip		

	NUMBER	TITLE
GROUP	3	SYMMETRY
STATION	3.2.1.2	ROTATION SYMMETRY 2
TOPIC		Rotation symmetry

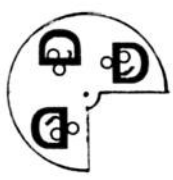
ROTATION SYMMETRY

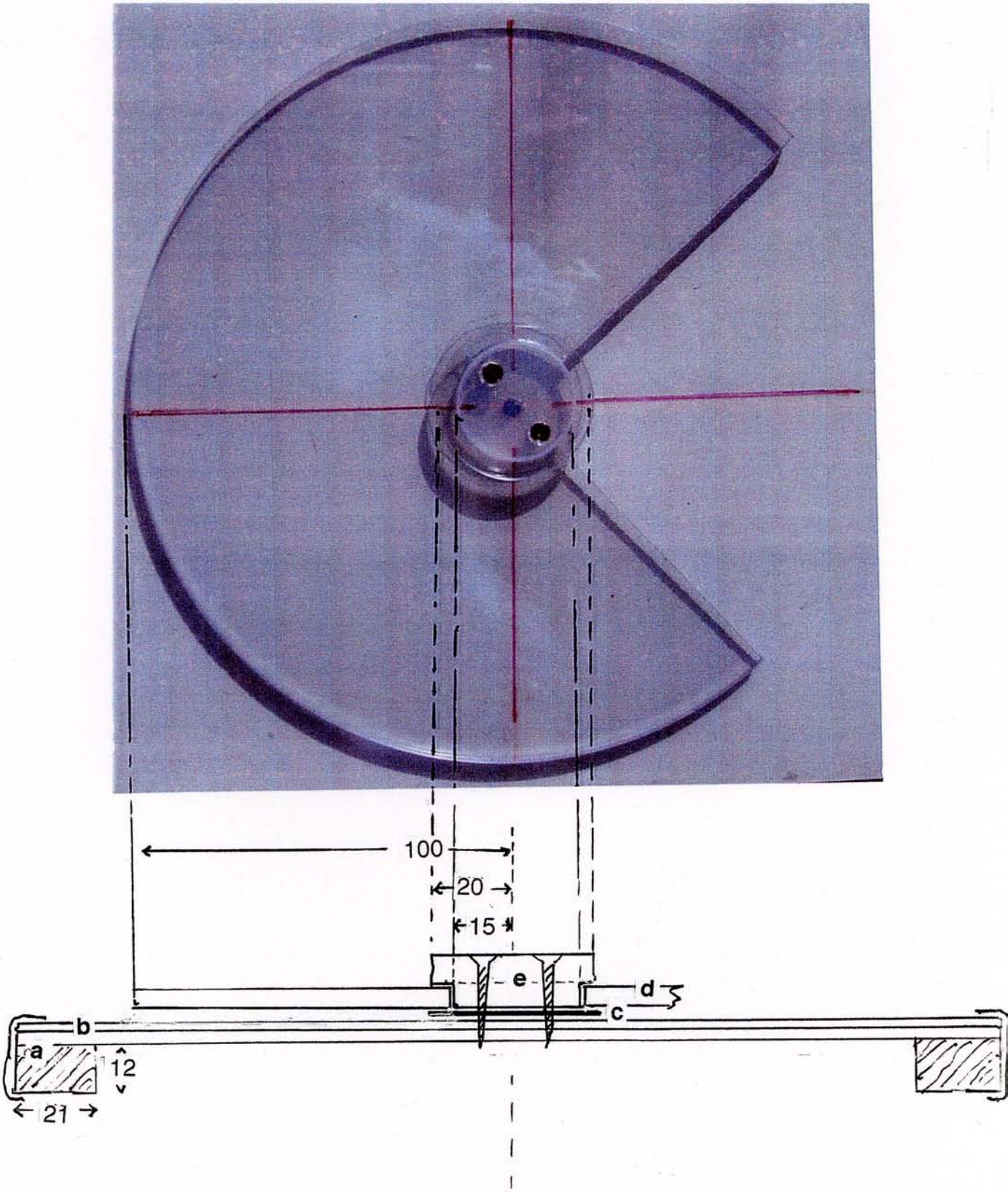
- Choose a disk.

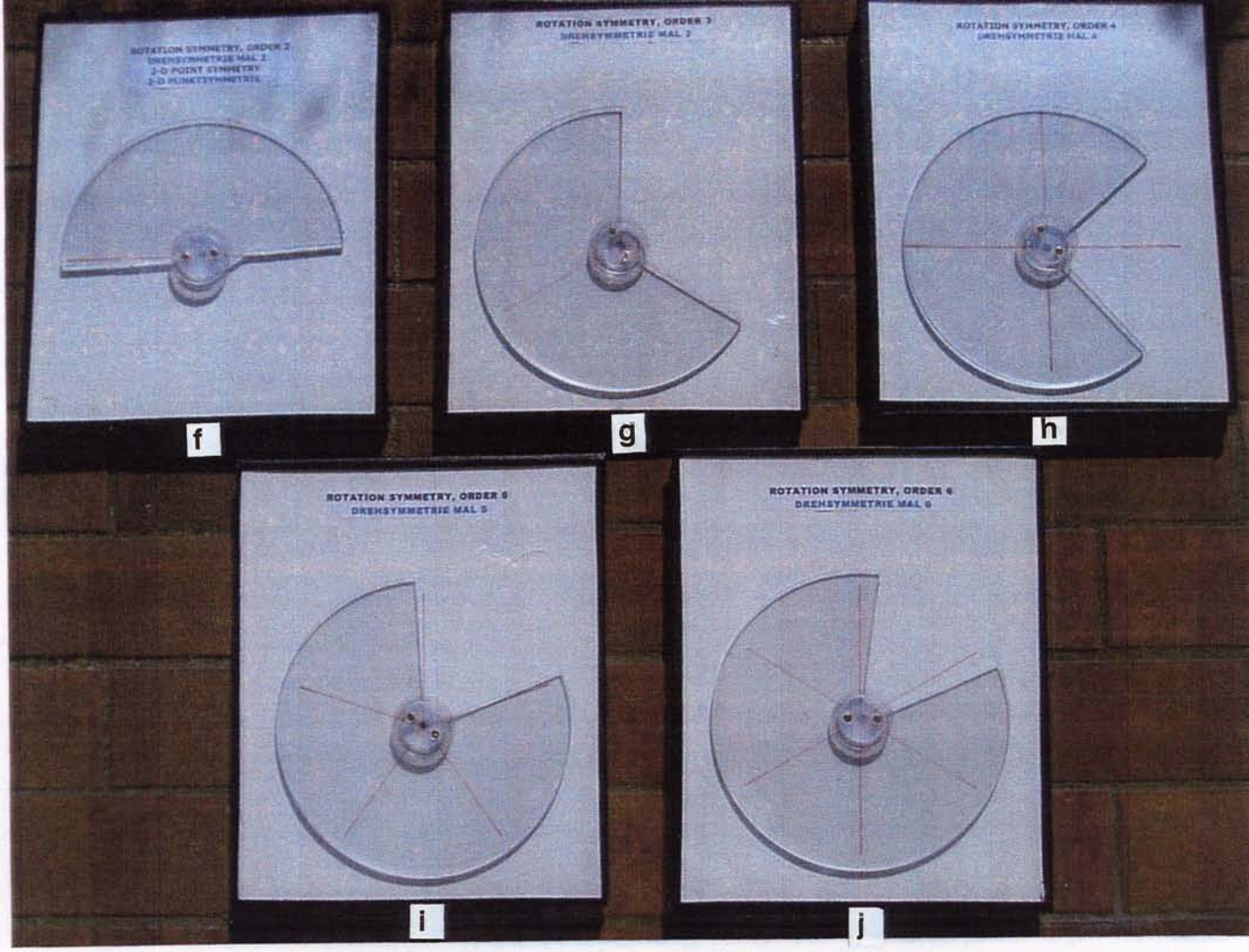
- Make a drawing in the cut-out.

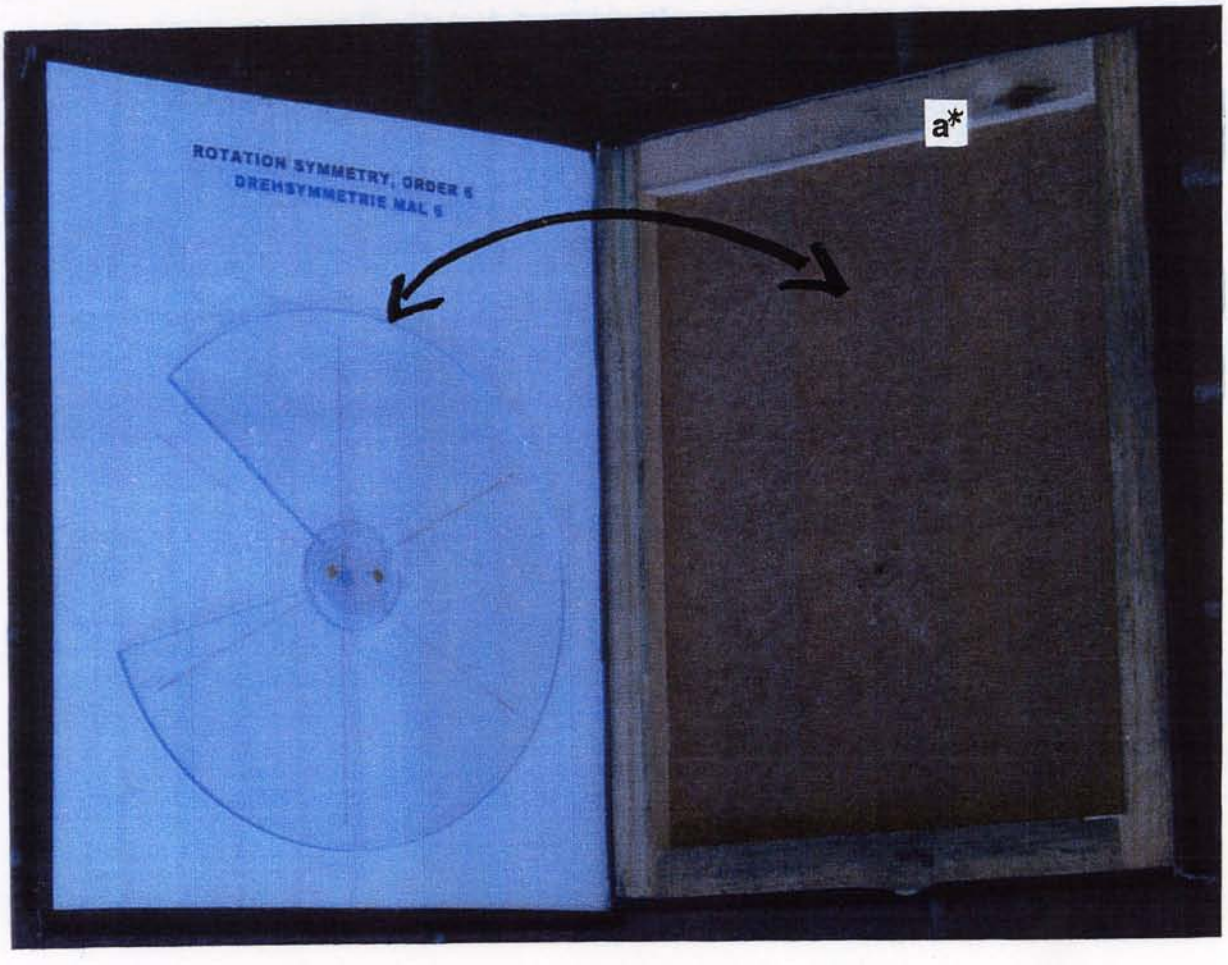
- Swing the disk over the top.
- Trace your drawing.

- Repeat till you have completed a design with rotation symmetry.




100
20
15
e
d
c
b
a
12
21


ROTATION SYMMETRY, ORDER 2
DREHSYMMETRIE MAL 2
2-D POINT SYMMETRY
2-D PUNKTSYMMETRIE
f
ROTATION SYMMETRY, ORDER 3
DREHSYMMETRIE MAL 3
g
ROTATION SYMMETRY, ORDER 4
DREHSYMMETRIE MAL 4
h
ROTATION SYMMETRY, ORDER 5
DREHSYMMETRIE MAL 5
i
ROTATION SYMMETRY, ORDER 6
DREHSYMMETRIE MAL 6
j


ROTATION SYMMETRY, ORDER 6
DREHSYMMETRIE MAL 6
a*

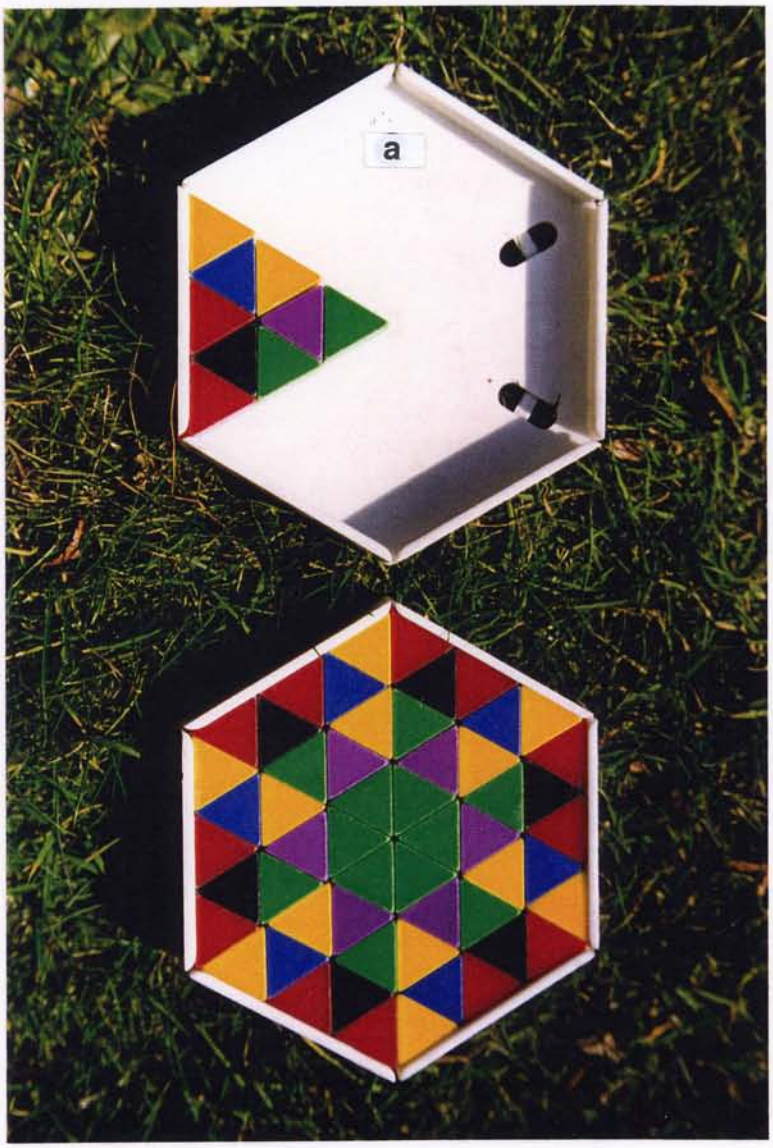
PICTURE KEY	DESCRIPTION	TRADE NAME	U.K. SOURCE
a	caption board as described, bearing artwork shown, mounted on wooden frame		local
a*	showing same The picture shows the purpose of the frame, namely to protect the disk below when the units are stacked. A blank version of **a** completes the stack, which is secured with rubber bands.		
b	Glodex, 2 mm, to fit **a**, taped in place (as for a standard caption board)		
c	disk of 300 micron acetate sheet, 20 mm radius, as a spacer		
d	disk, Glodex, 4 mm, 100 mm radius, hole, radius 15 mm at centre, sector with angle specified below cut out		
e	boss, consisting of disks of Glodex, 4 mm, with radii 15 mm, 20 mm, cemented together, secured to **a** by 2 wood screws through **c**; length of these countersunk: between 8 and 12 mm therefore		
f-j	sectors cut out according to the order of rotation symmetry as follows: 2: 180° 3: 120° 4: 90° 5: 72° 6: 60° Note that in the case of **f** a small piece must be left partly circling the boss on one side or both.		

	NUMBER	TITLE
GROUP	3	SYMMETRY
STATION	3.2.2	ROTATION SYMMETRY 3
TOPIC		As 3.2.1

ROTATION SYMMETRY

- Take a tray.
- Make a motif with 9 prisms.
- ▶ Your motif should NOT have MIRROR SYMMETRY.
- Swap trays.
- Repeat your partner's motif round the tray so that the finished design has ROTATION SYMMETRY ORDER 6.

- Now do the same with 18 prisms.
- ▶ This time your design should have ROTATION SYMMETRY ORDER 3.
- Now do the same with 27 prisms.
- ▶ This time your design should have ROTATION SYMMETRY ORDER 2.


a

PICTURE KEY	DESCRIPTION	TRADE NAME	U.K. SOURCE
a	hexagonal trays with coloured prisms to fit	Prismo (see **3.1.1 j**)	

	NUMBER	TITLE
GROUP	3	SYMMETRY
STATION	3.3	POINT SYMMETRY
TOPIC		As title

POINT SYMMETRY

- A shape with 'point' symmetry has a special point or 'centre'. Each point on the shape is reflected in the centre to produce a matching point.

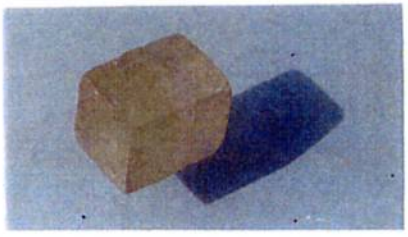
- Point symmetry in 2 dimensions is the same as half-turn symmetry, rotation symmetry order 2.

- Hold the playing card between 2 fingers and give it a half-turn.

- Does it come to the same position?

- Draw such a design on the special disk.

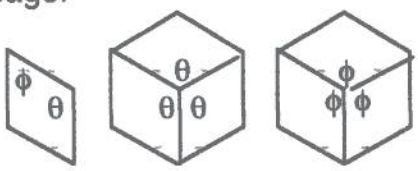
- Is the same necessarily true in 3-D?



- Hold the crystal between 2 fingers and give it a half-turn.

- Does it come to the same position?

- Build a Polydron model with only this symmetry.

PICTURE KEY	DESCRIPTION	TRADE NAME	U.K. SOURCE
	Needed:		
	1 'face' playing card		local
	1 calcite crystal		local museum shop or specialist 'rocks and minerals' shop
	10* rhombic tiles	Polydron, cat. no.: 10-0404	Polydron International Ltd (address above)
	* The Polydron rhombus has diagonals in the ratio $\sqrt{2}$:1 and therefore $\theta < 2\pi/3$. This makes it possible to build 2 distinct rhombohedra. However, both have 3-axes, here normal to the page:  $\phi = \pi - \theta$ Therefore, to build a parallelepiped without such axes, some faces - necessarily 4, 2 sets of 2 - must be parallelograms with unequal sides. The modellers will need at least 2 rhombuses to make such a parallelogram. Therefore they will need at least 2 + 4(2) = 10 in all.		

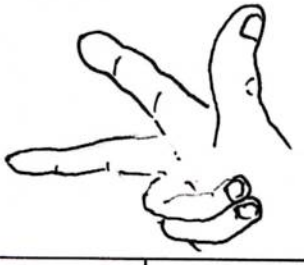
	NUMBER	TITLE
GROUP	3	SYMMETRY
STATION	3.4	YOU AND YOUR REFLECTION
TOPIC		Mirror, rotation and point symmetry

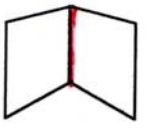
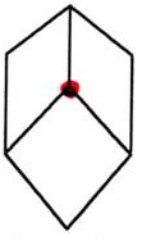
YOU & YOUR REFLECTION

- **Use yourself and these mirror groups to make 3 pairs of people, each with a different symmetry.**

Either:
Look straight in, holding one ear.

Or:
Point in, like this:



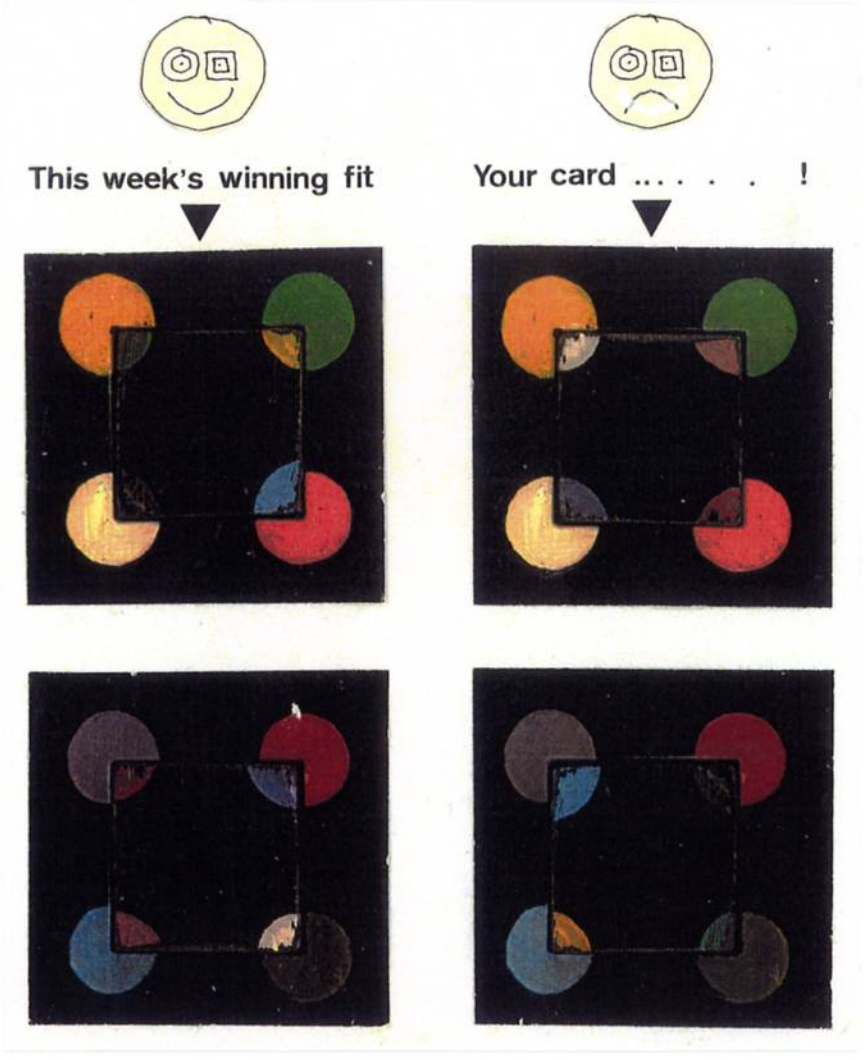
Group	1	2	3
	 1 plane mirror	 2 plane mirrors at right angles	 3 plane mirrors at right angles
The transformation you experience	Reflection in a PLANE	Reflection in a LINE	Reflection in a POINT
The symmetry of you-+-your-reflection	MIRROR	HALF-TURN	POINT

PICTURE KEY	DESCRIPTION	TRADE NAME	U.K. SOURCE
	6 mirror squares as **3.1.3 c**, taped in groups as on caption		

	NUMBER	TITLE
GROUP	3	SYMMETRY
STATION	3.5	ORDER OF SYMMETRY
TOPIC		As title

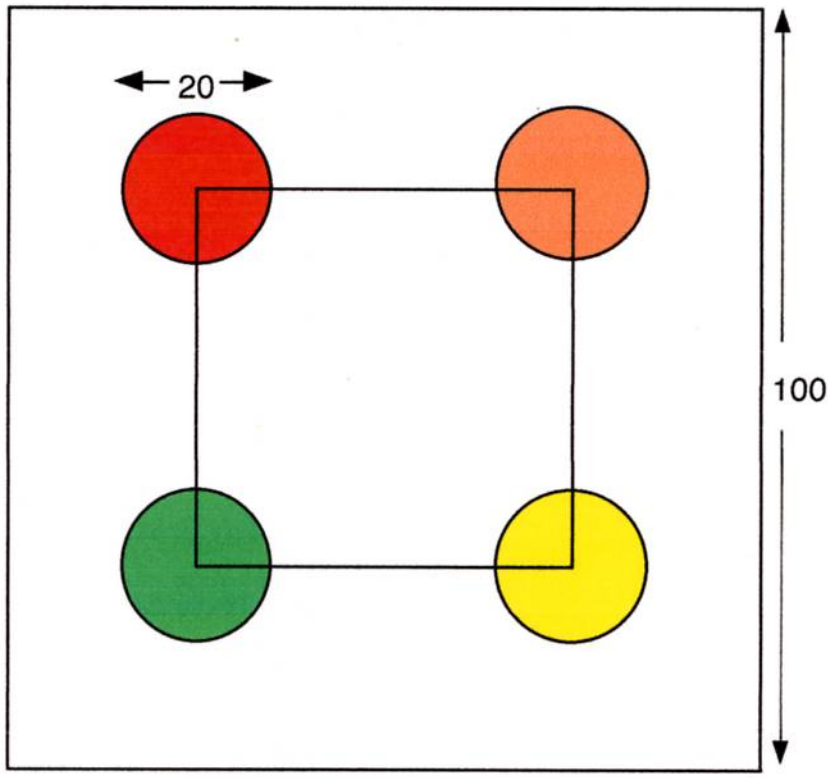
ORDER OF SYMMETRY:
THE MAGIC MATHWORKS LOTTERY MACHINE

▶ **A trained hamster rolls the cube about then drops it into the hole.**

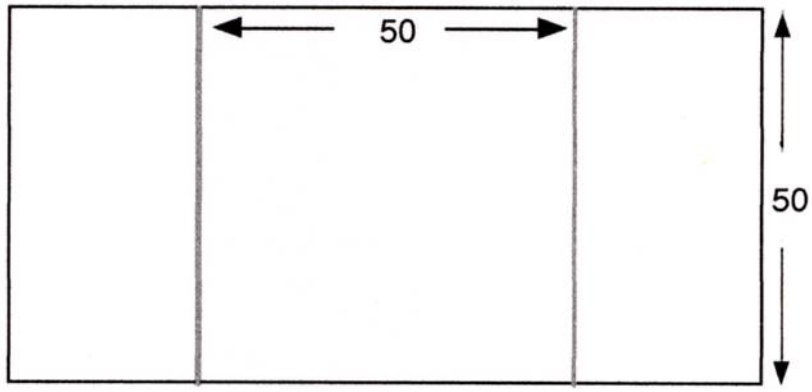


■ **What chance had you of winning?**
In other words,
In how many ways does the cube fit the hole?

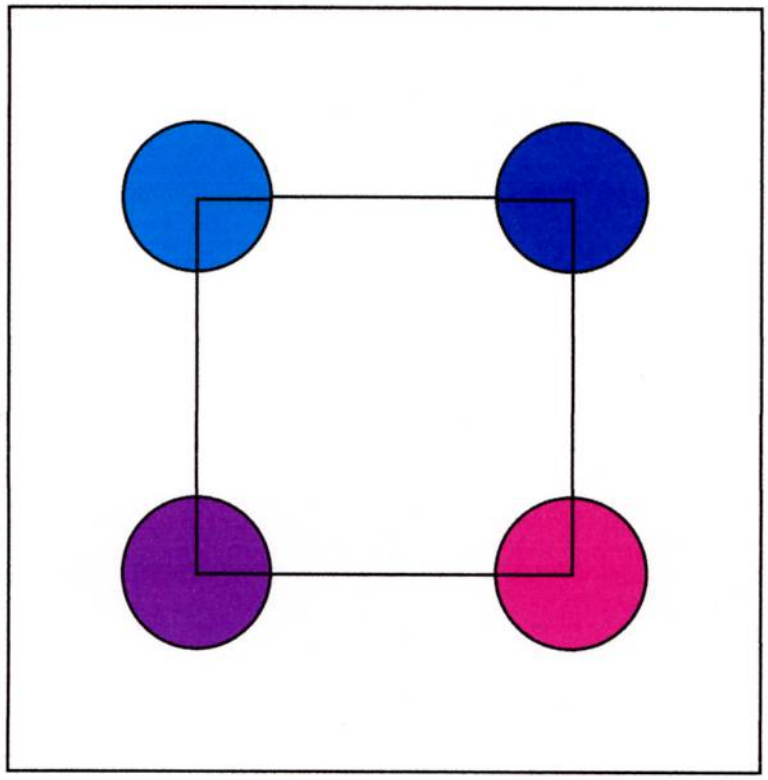
PLAN: TOP



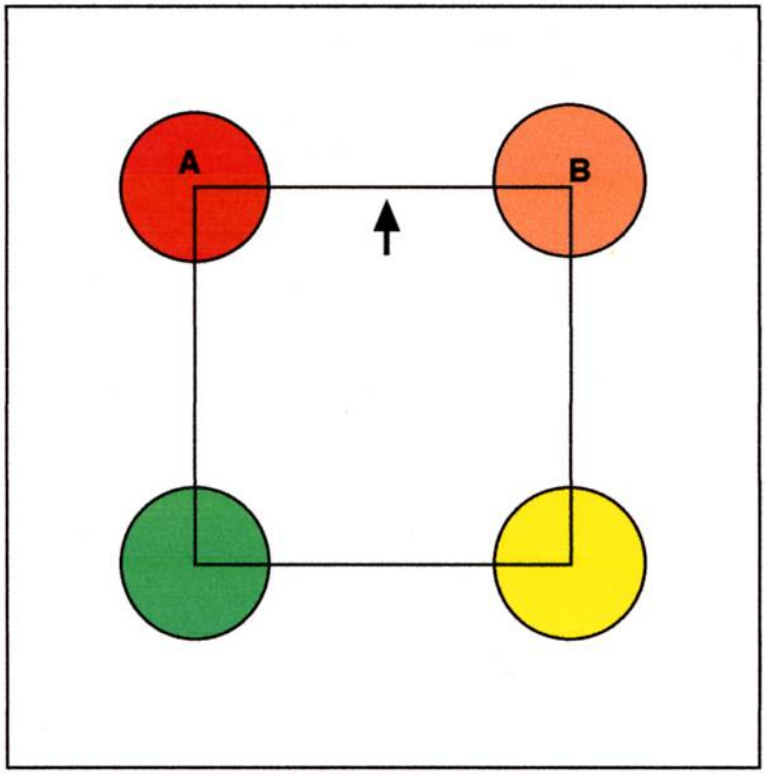
ELEVATION

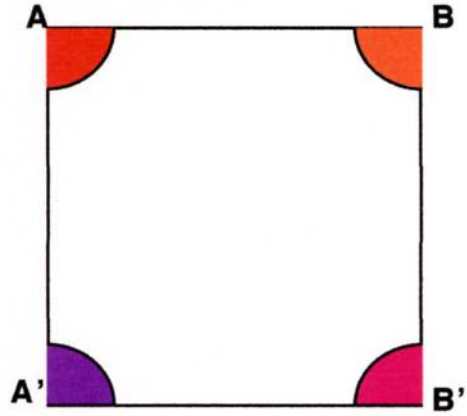


PLAN: BOTTOM



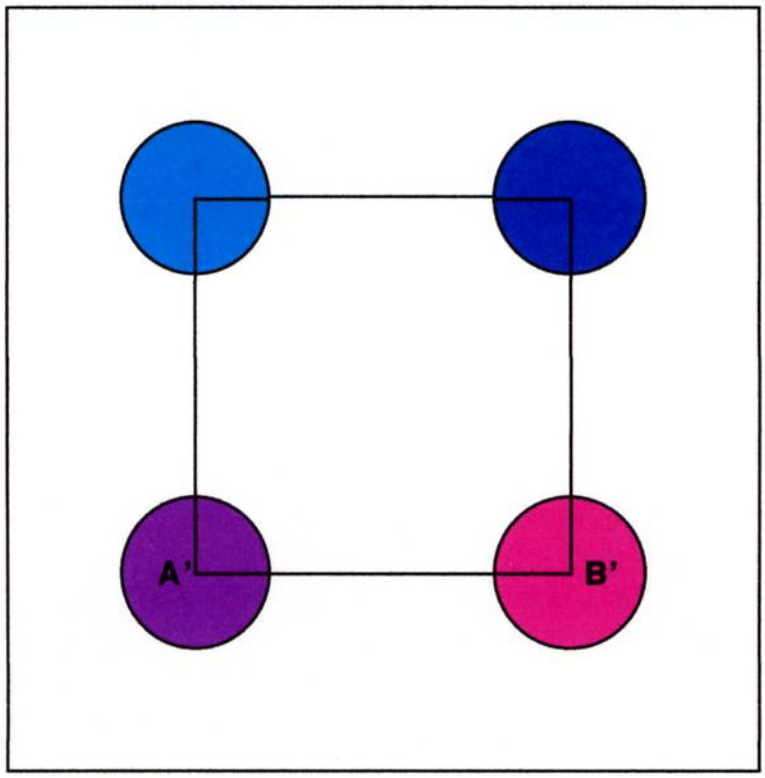
PLAN: TOP





ELEVATION

PLAN: BOTTOM



PICTURE KEY	DESCRIPTION	TRADE NAME	U.K. SOURCE
	The caption and the drawings following show a wooden cube and a frame into which it can be inserted. (This may be painted either black, as on the caption, or white, as in the drawings.) Each vertex of the cube and the corresponding one in the frame is to be thought of as part of a sphere and given 1 of 8 distinct colours. Thus, in the elevation of the back wall of the frame, we see a coloured quadrant at each corner. The coloured quadrants on the face of the cube in contact with it match. The point of the investigation is that there are 23 further orientations of the cube which cause different colours to pair up on the cube and in the frame, i.e. 24* in all. *Each of the 8 cube vertices can match, say, the red frame vertex. With this restriction, rotation about a 3-axis into 3 positions is possible, giving a total of 8 x 3 = 24 combinations. Equivalently, each of the 6 cube faces can be at the top. With this restriction, rotation about a 4-axis into 4 positions is possible, again giving a total of 6 x 4 = 24 combinations. Equivalently, each of the 12 cube edges can match, say, the top back frame edge. With this restriction, rotation about a 2-axis into 2 positions is possible, again giving a total of 12 x 2 = 24 combinations.		local

	NUMBER	TITLE
GROUP	3	SYMMETRY
STATION	3.6-7	SYMMETRICAL PUZZLES
TOPIC		Mirror, rotation and central symmetry

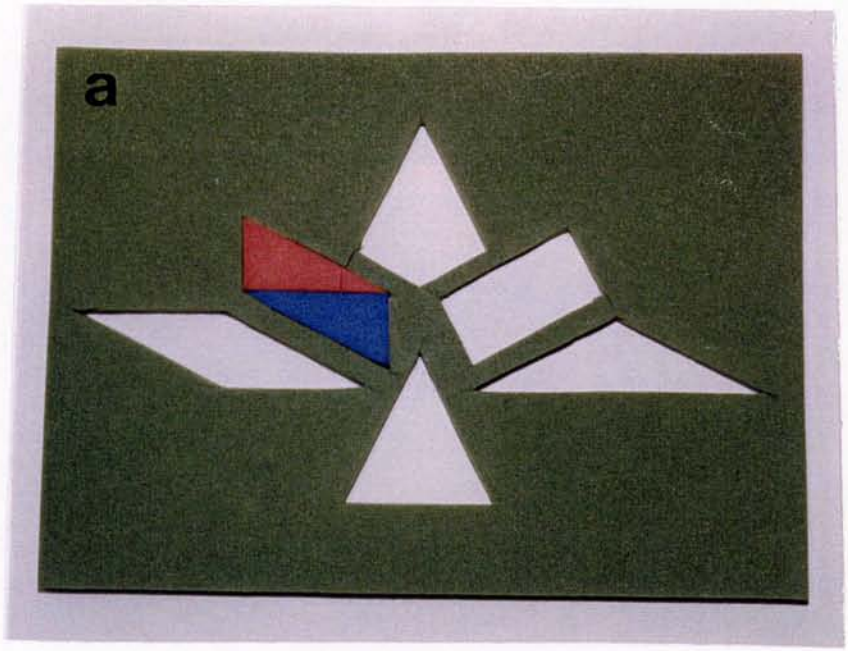
SYMMETRICAL PUZZLES

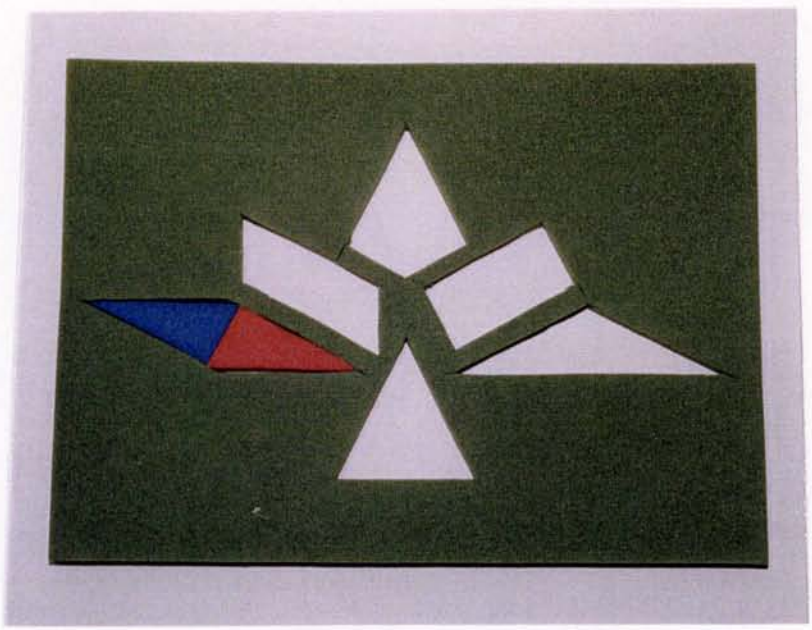
- **Use SYMMETRY to help you solve these dissection puzzles.**

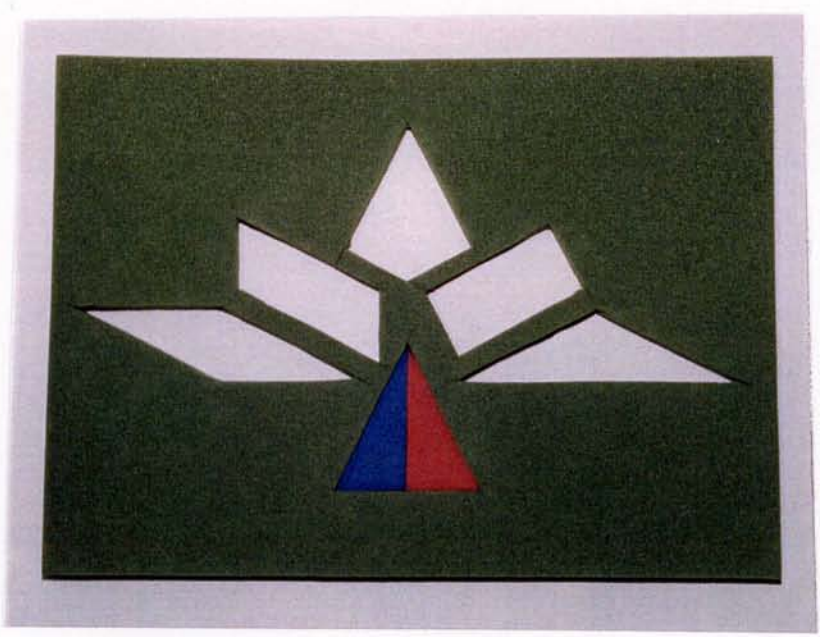
- **Ask yourself two questions:**

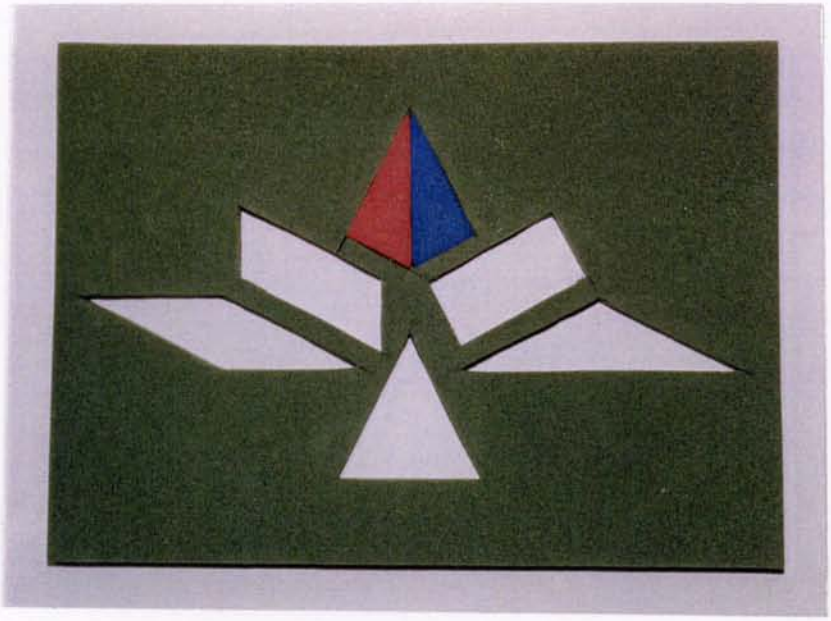
  - **How many pieces of each shape have I got?**

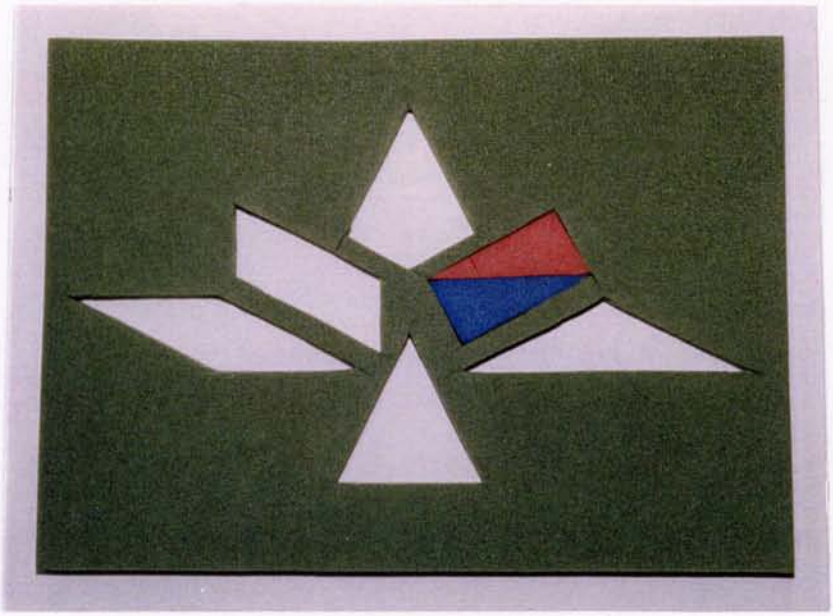
  - **How, therefore, must they be arranged?**

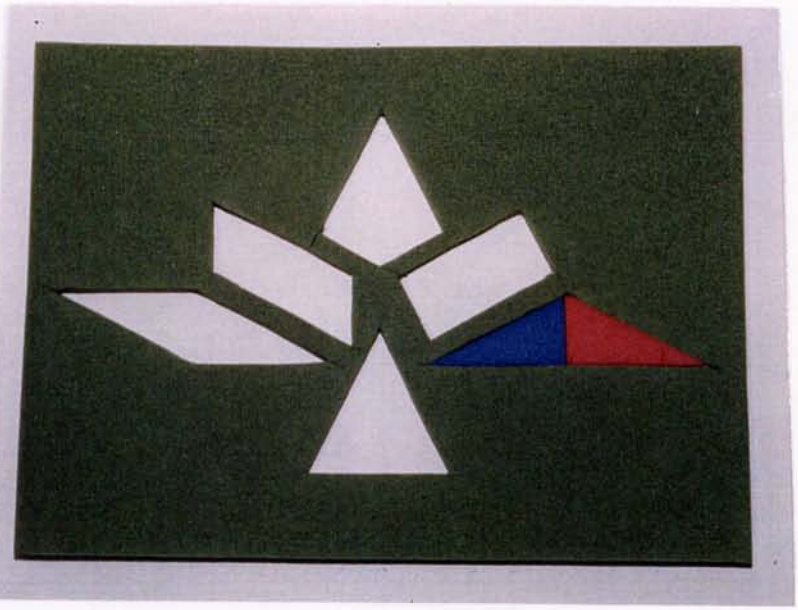

a

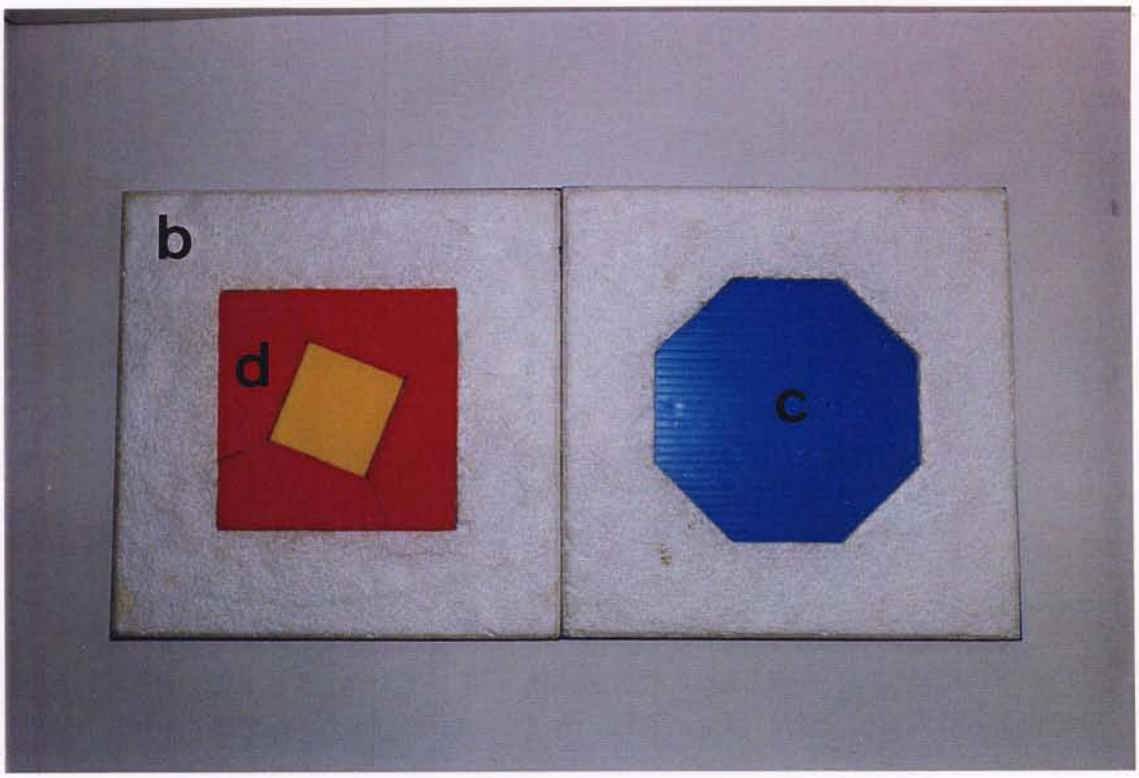


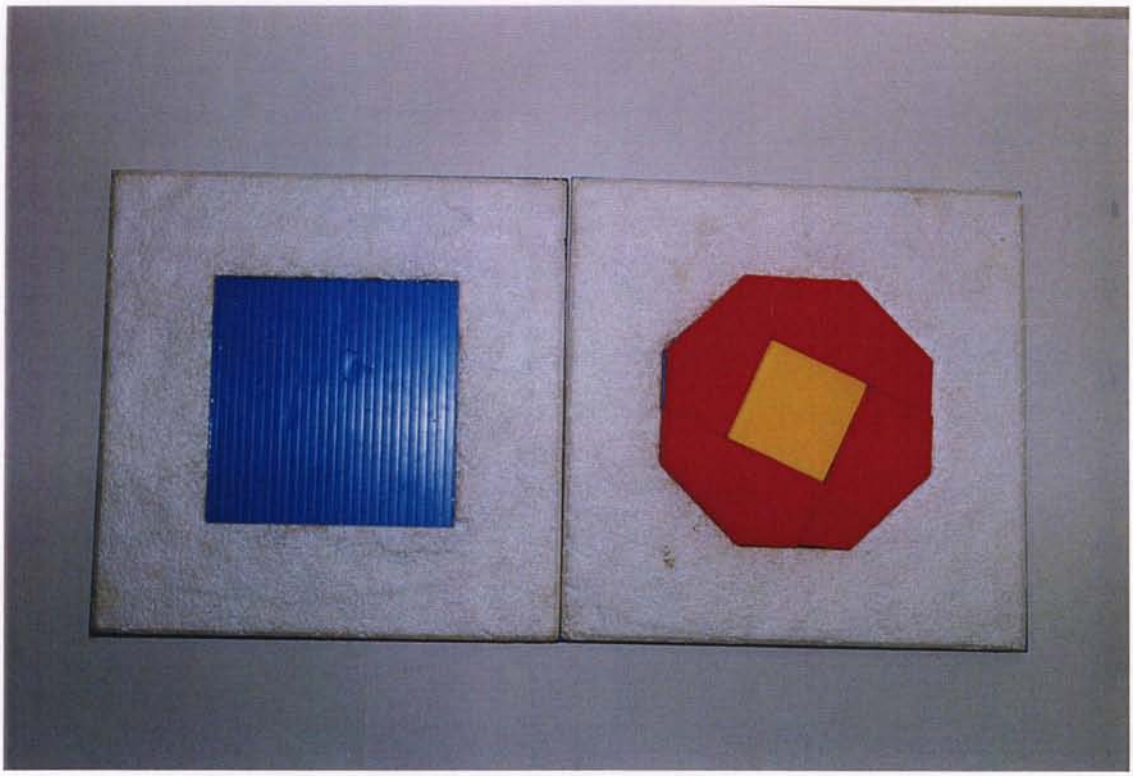


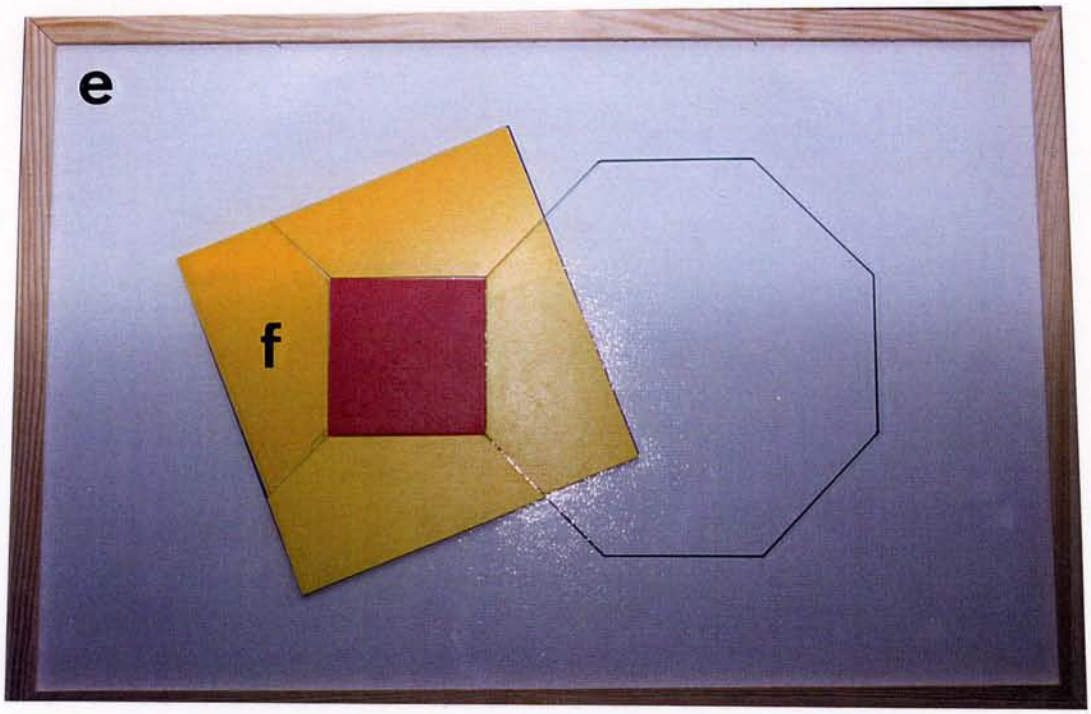







b
d
c




e
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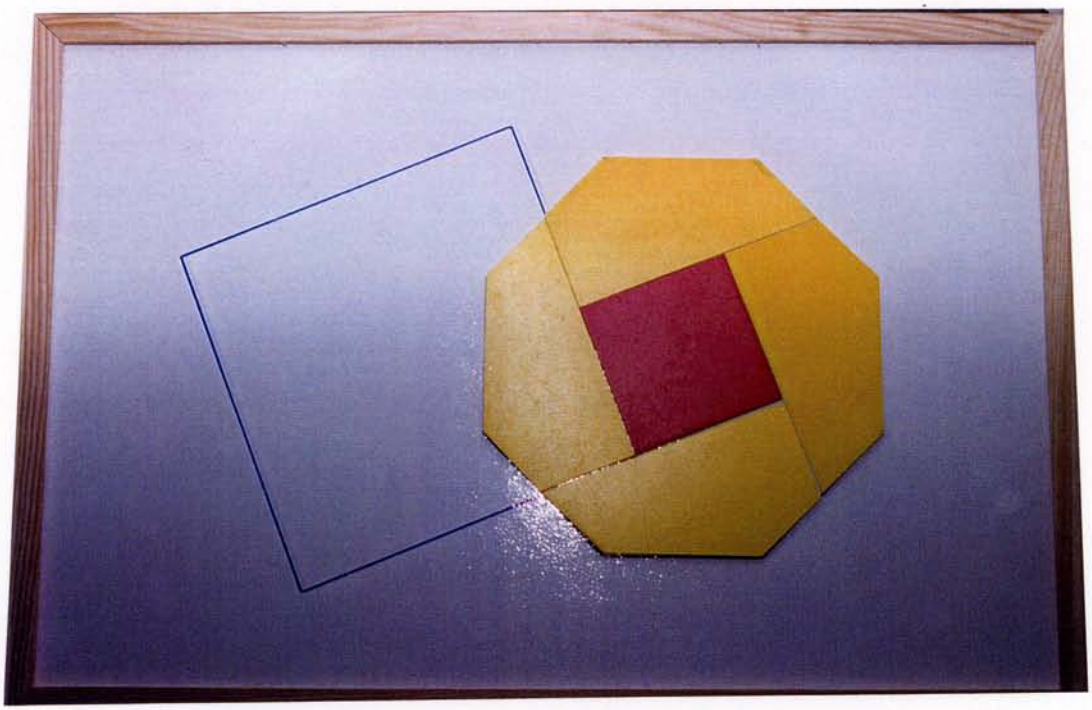
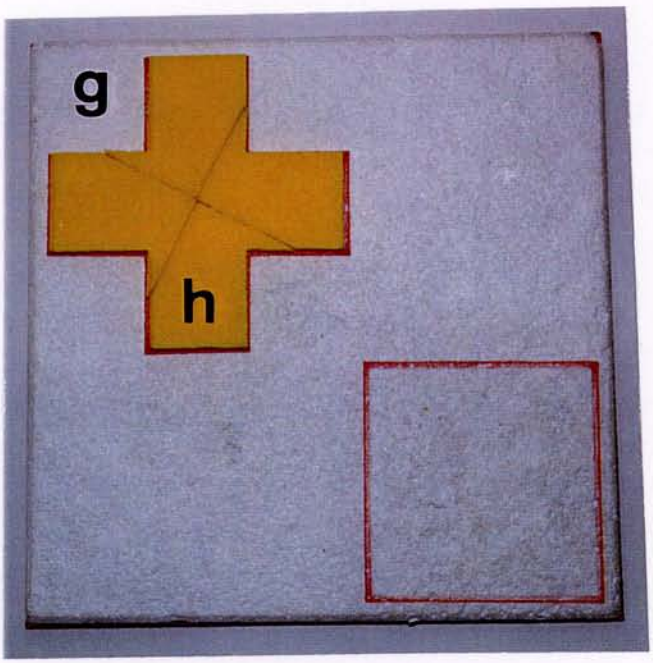
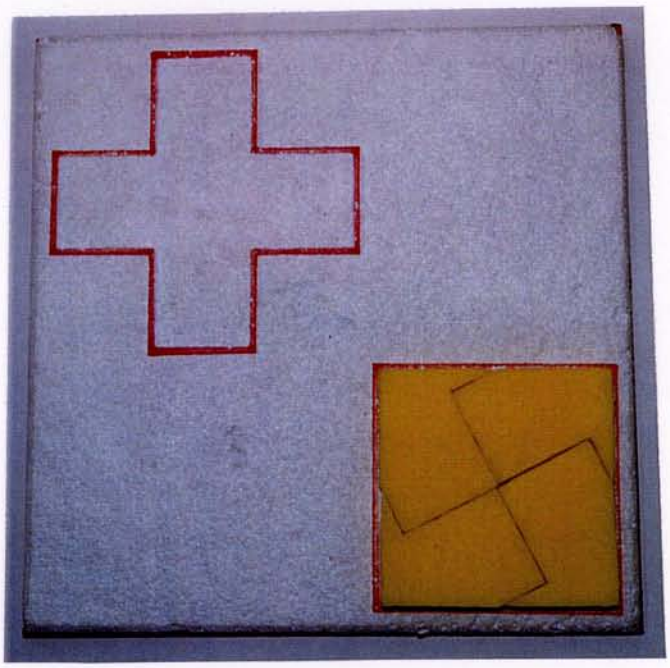
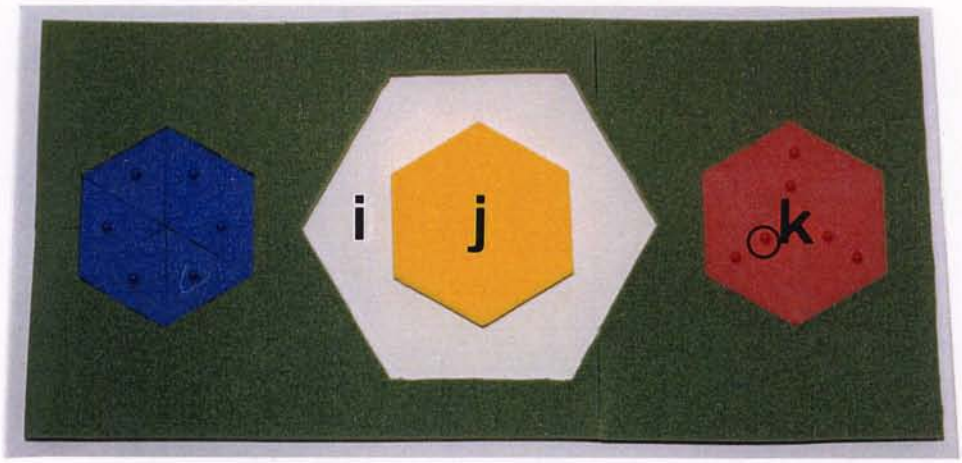
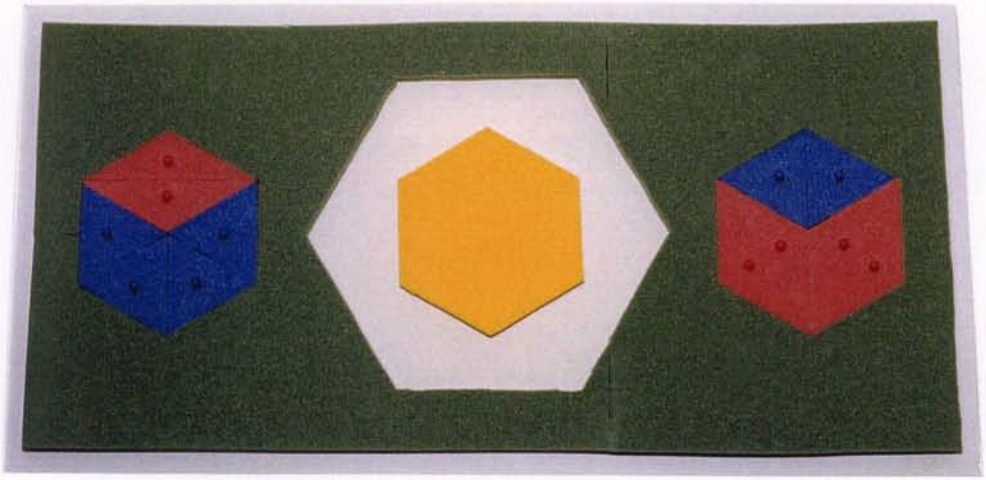
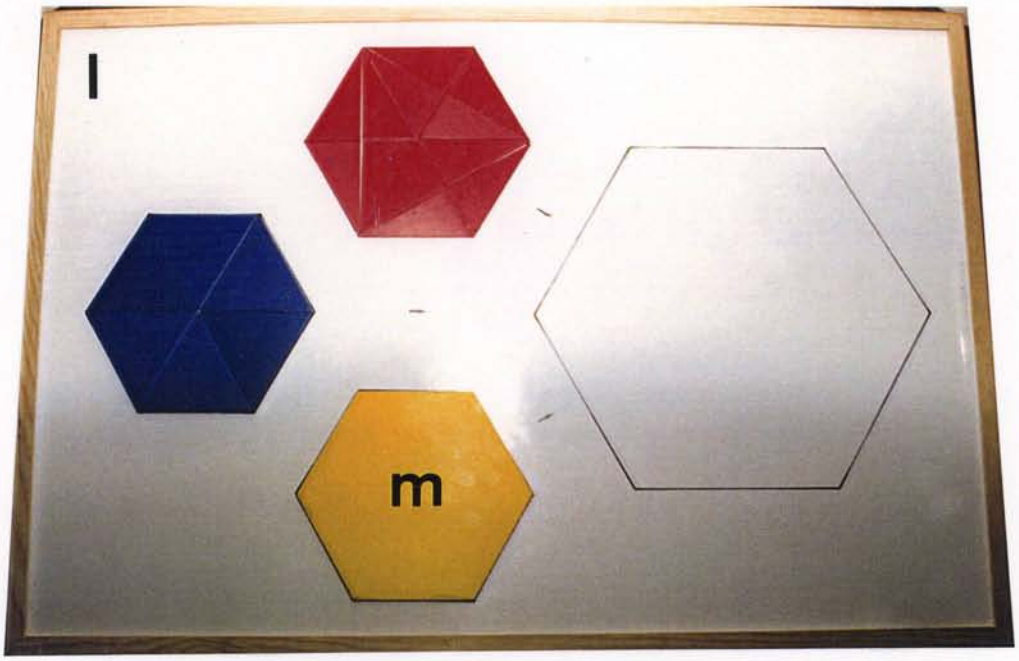


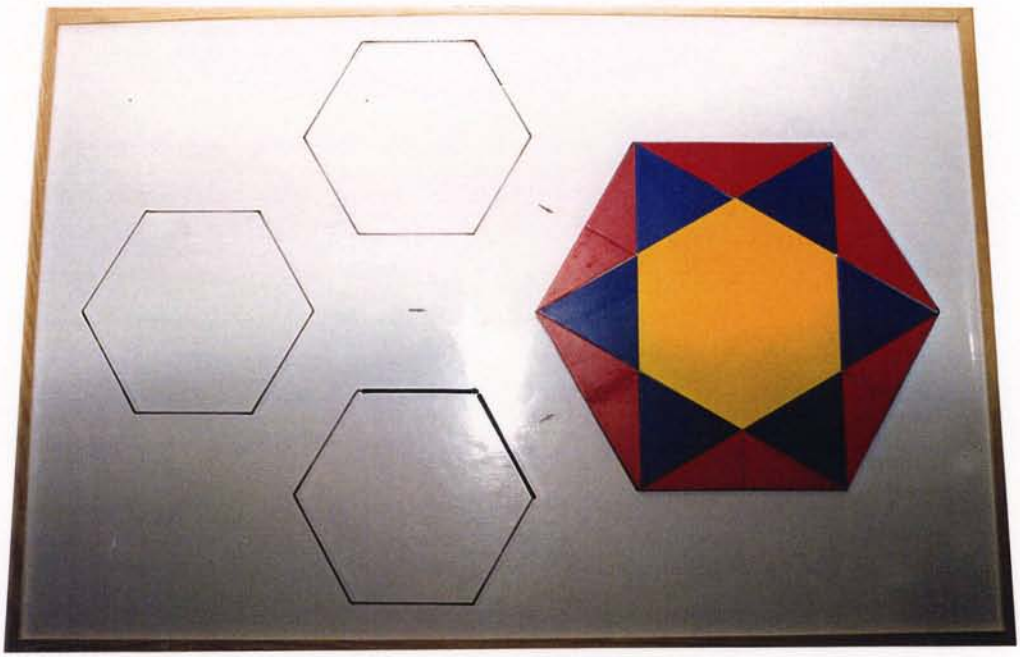

g
h

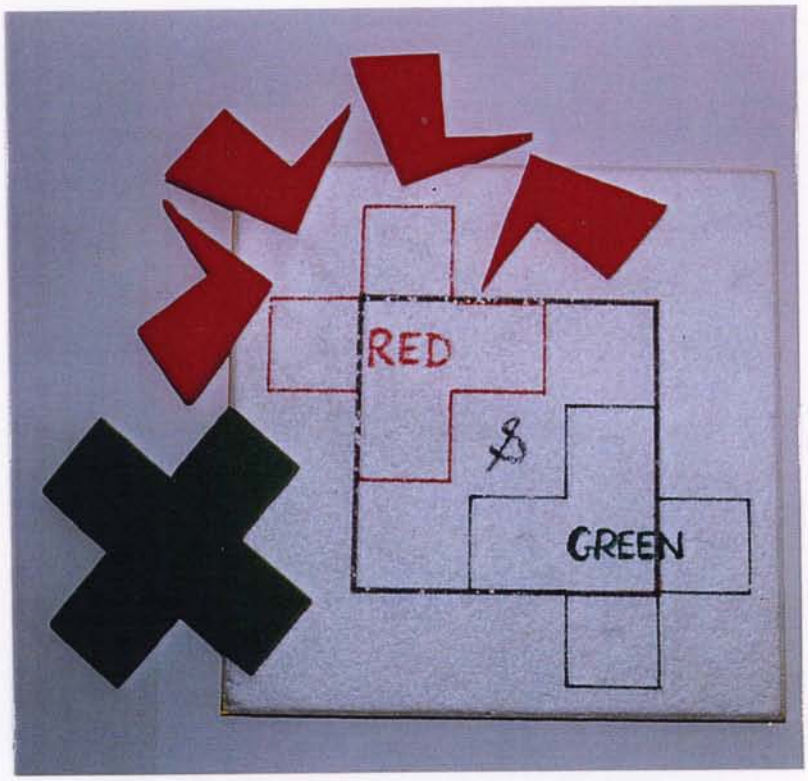


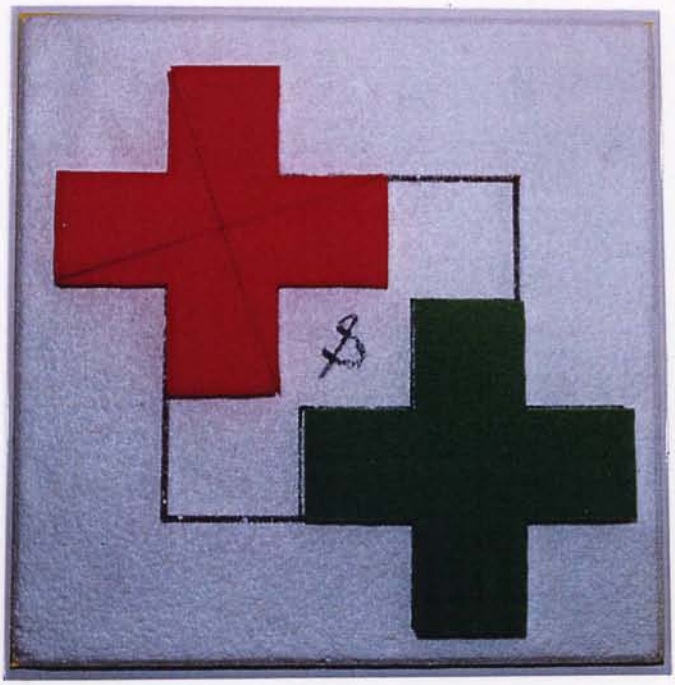

i
j
k

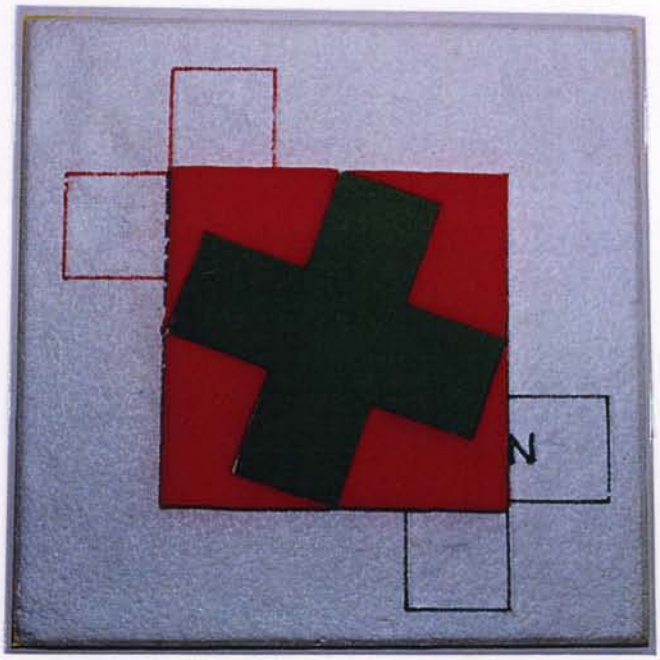



l
m

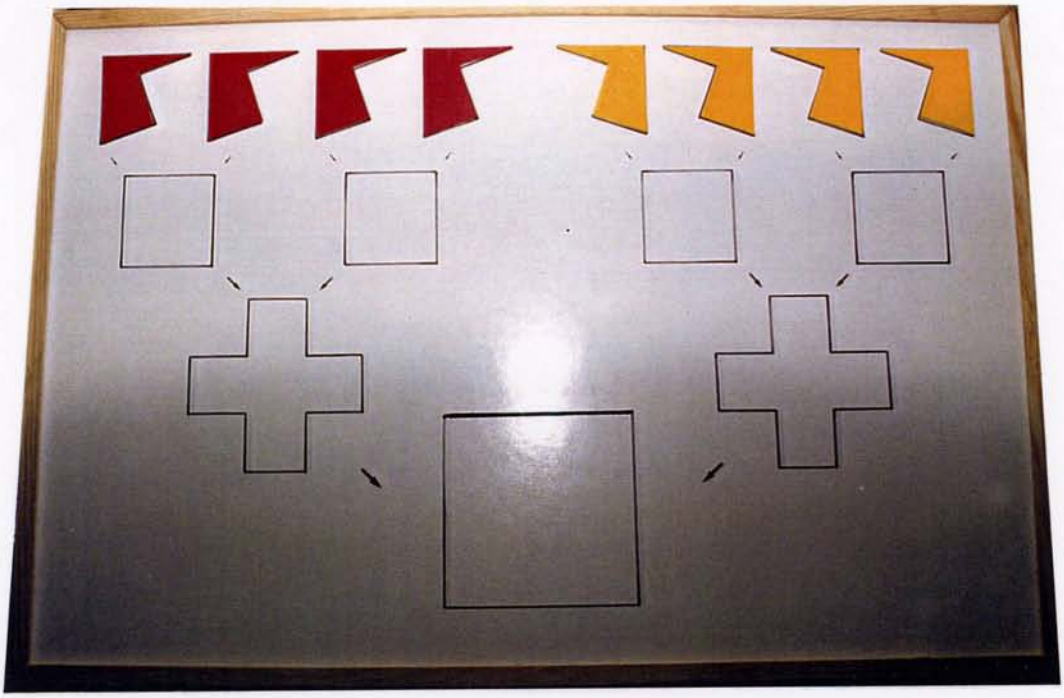


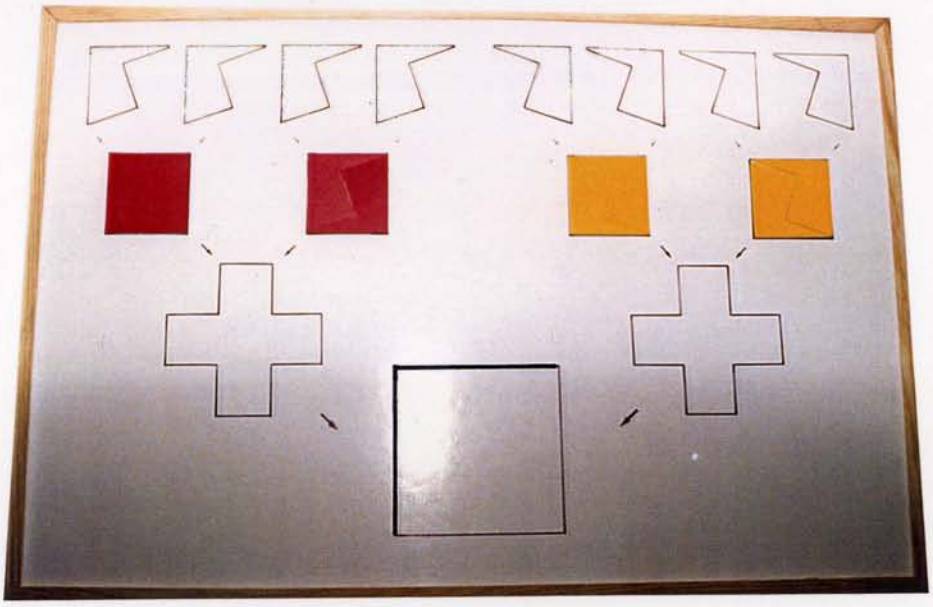

RED
GREEN

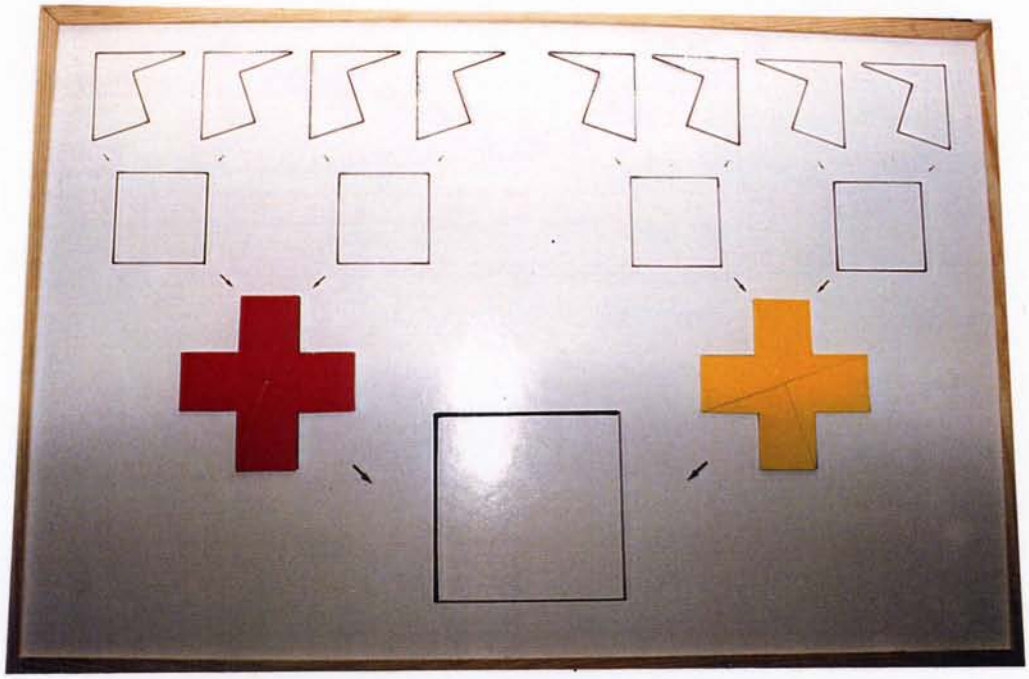


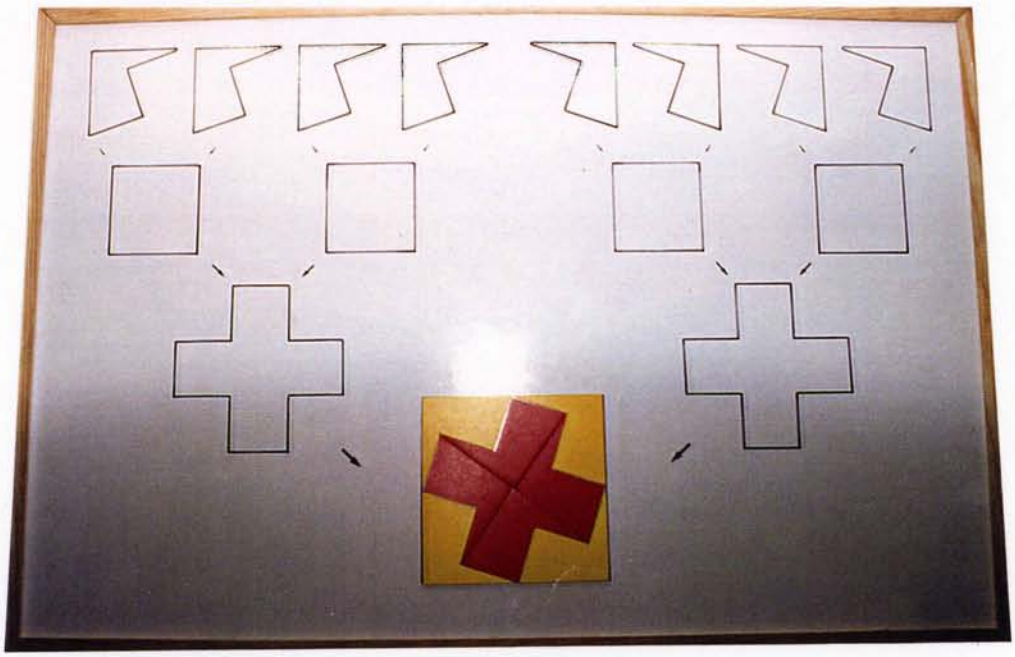


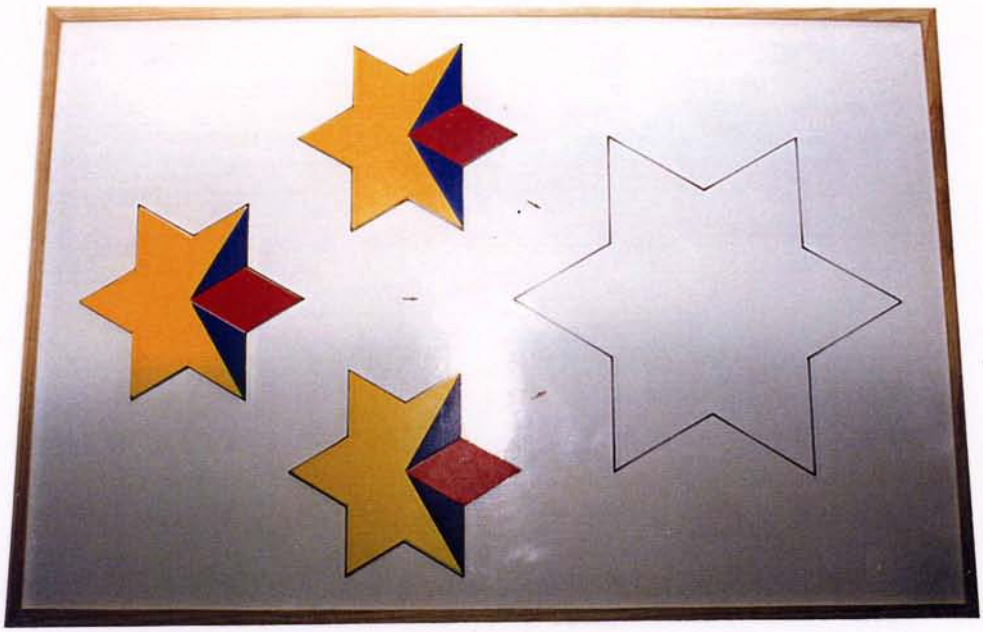
3.6.5 B

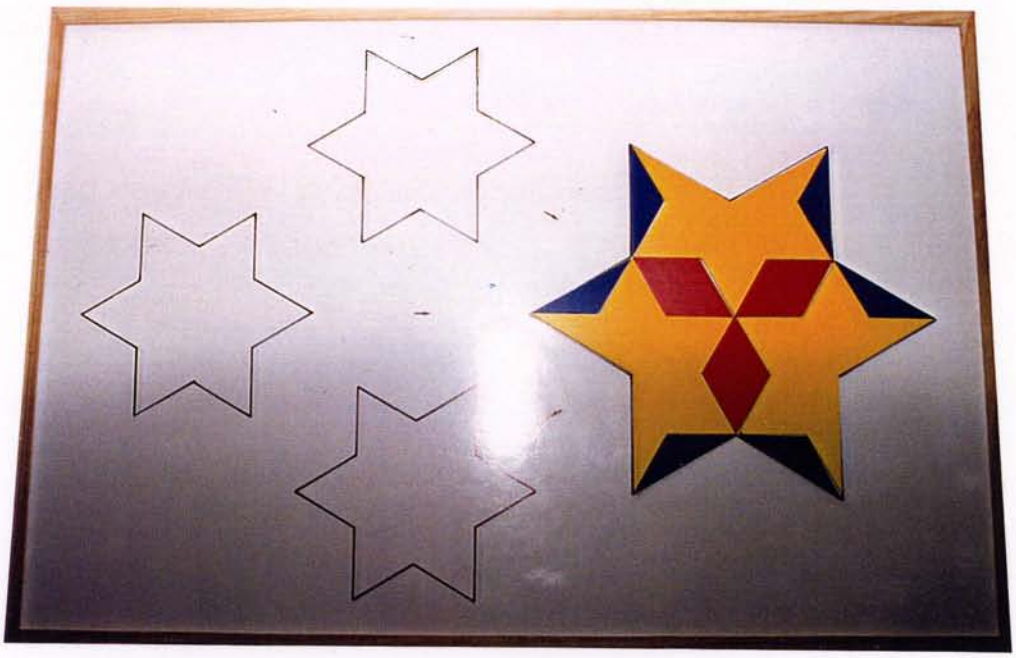


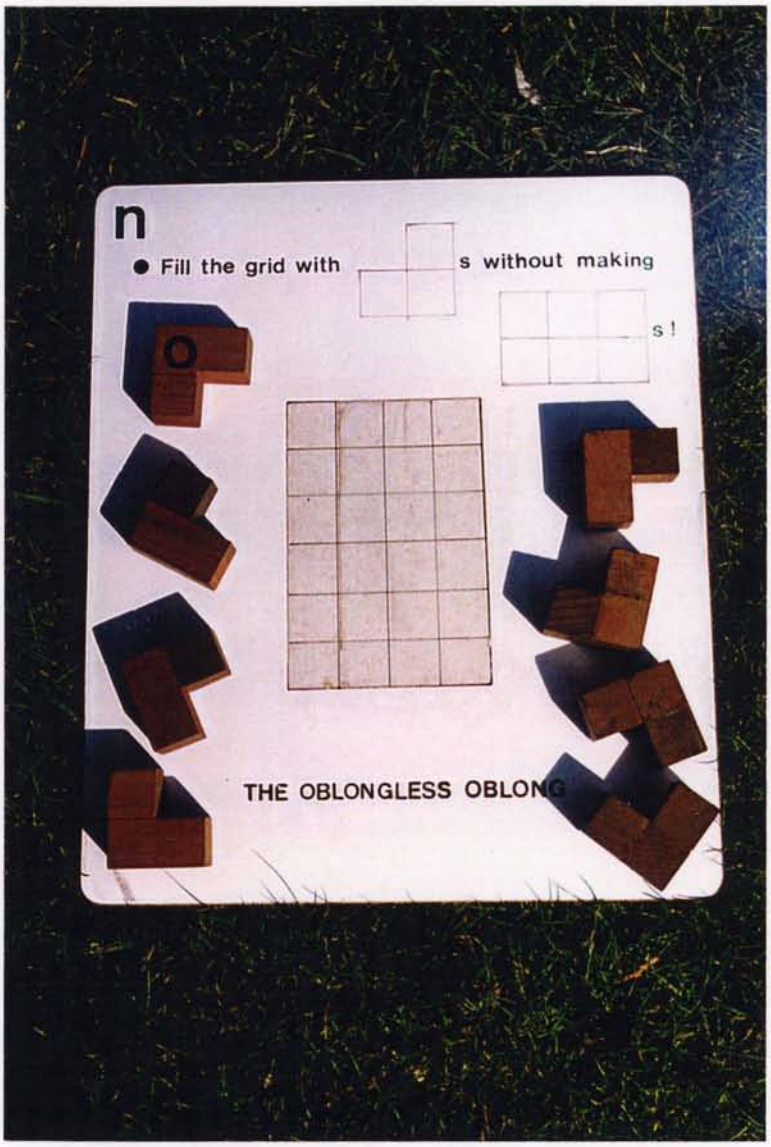








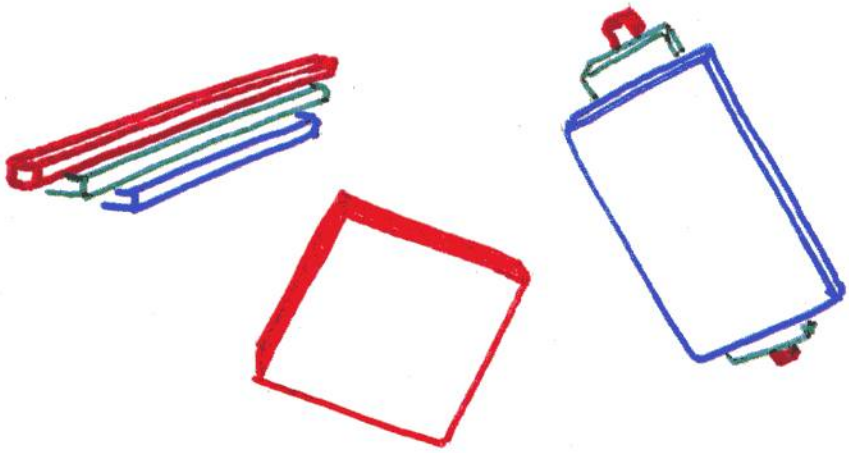



n
● Fill the grid with
s without making
s !
THE OBLONGLESS OBLONG

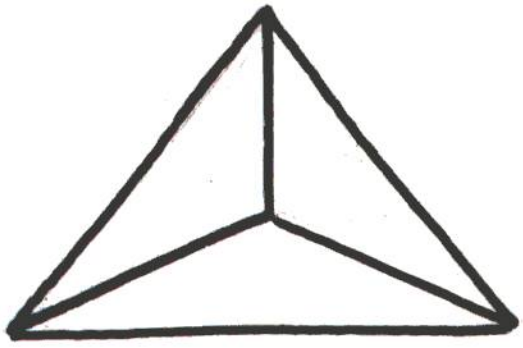
PICTURE KEY	DESCRIPTION	TRADE NAME	U.K. SOURCE
3.6.1 - 3.6.6	Reproduce templates from the Magic Mathworks **DISSECTIONS** file.		The Magic Mathworks (address above)
3.6.1 a	expanded polyethylene, 6mm, A4. (This must be ordered in bulk. For small quantities use Magic Mathworks off-cuts.)		v.s.
3.6.2A			
b	expanded polystyrene, 6 mm, 300 mm square, as ceiling tile, varnished with polyvinyl acetate (PVA), e.g.:		local
		Alocryl medium	
		NES Arnold catalogue: KA 506/3	NES Arnold Ltd (address above)
c	corriflute	NES Arnold catalogue: FI 681/8	v.s.
d	expanded polyethylene as described		
3.6.2B			
e	dri-wipe notice board, 650 mm x 450 mm		local
f	PVC, 3 mm	Amari Foam, 3 mm	Amari Plastics Shenstone Trading Estate Bromsgrove Road Halesowen West Midlands B63 3XB T +44 121 550 9971 F +44 121 550 3476
3.6.3 g	ceiling tile as described		
h	expanded polyethylene as described		
3.6.4A			
i	2 sheets of white-faced hardboard stuck back-to-back, 600 mm x 300 mm		local
j	expanded polyethylene as described		
k	mapping pins as handles		local
3.6.4B			
l	dri-wipe notice board, 1000 mm x 650 mm		local
m	PVC as described		
3.6.5A	as **3.6.3**		
3.6.5B	as **3.6.4B**		
3.6.6	as **3.6.4B**		
3.6.7 n	caption board as described, marked as shown		
o	tricubes, made from 15 mm wood cubes		local

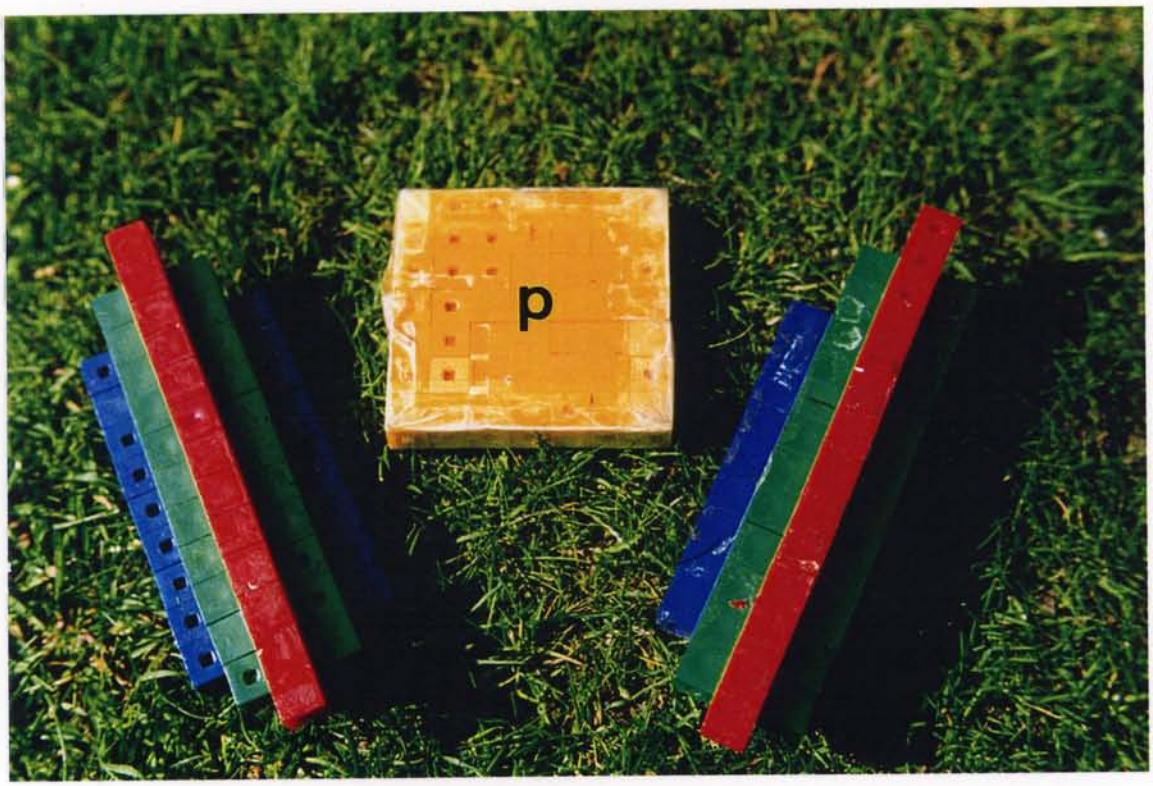
THE TETRAHEDRON PUZZLE

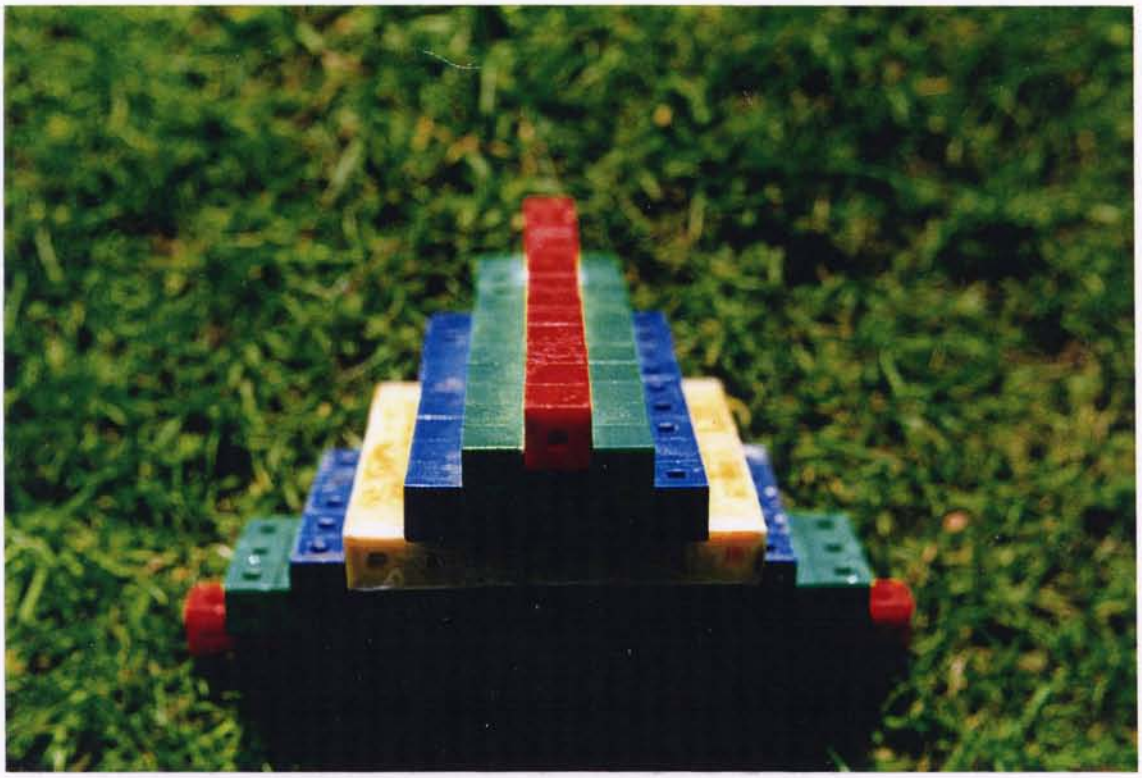
▶ **These ...**



make this:



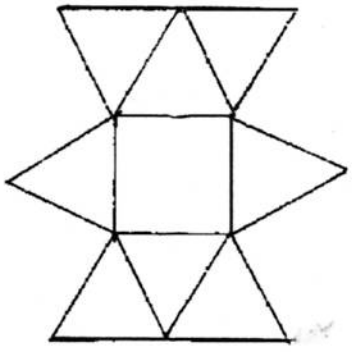

p

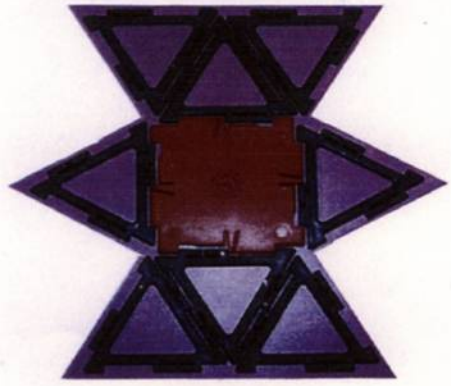


	NUMBER	TITLE
GROUP	3	SYMMETRY
STATION	3.7.1	THE 2-PIECE TETRAHEDRON
TOPIC		(Extension Activity)

THE 2-PIECE TETRAHEDRON

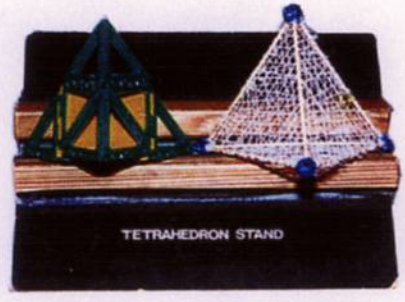
- **Set the perspex model in the black box and section it with light along the red line to show the SQUARE.**
- **Use Polydron to build the 2 identical pieces of a puzzle. Here is the net for each:**



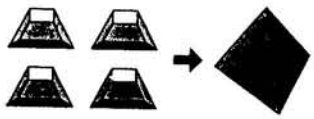



TETRAHEDRON STAND


TETRAHEDRON STAND

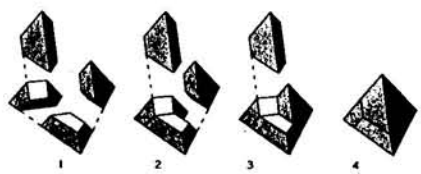

TETRAHEDRON STAND

THE 4-PIECE TETRAHEDRON
DAS 4-TEILE TETRAEDER



Die Lösung ist auf der anderen Seite.

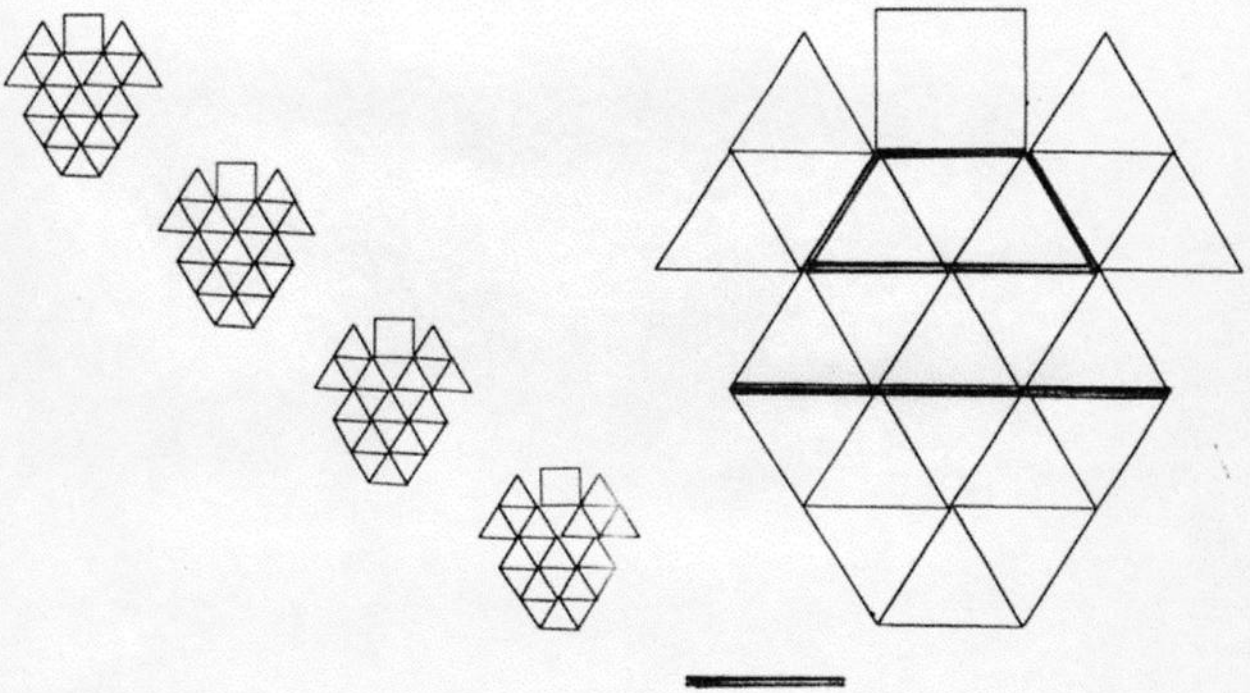
● **Turn over for the solution. ▼**



	NUMBER	TITLE
GROUP	3	SYMMETRY
STATION	3.7.2	THE 4-PIECE TETRAHEDRON
TOPIC		(Extension Activity)

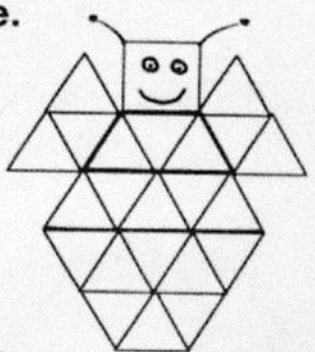
THE 4-PART TETRAHEDRON

- **Here is the net for each shape: Build 4.**



Hints on solving the puzzle:

- Thinking of the net as a bee, note that his chest and wings are the same shape. Butt a 'wing' against a 'chest'.



- Butt a 'head' against a 'head'.

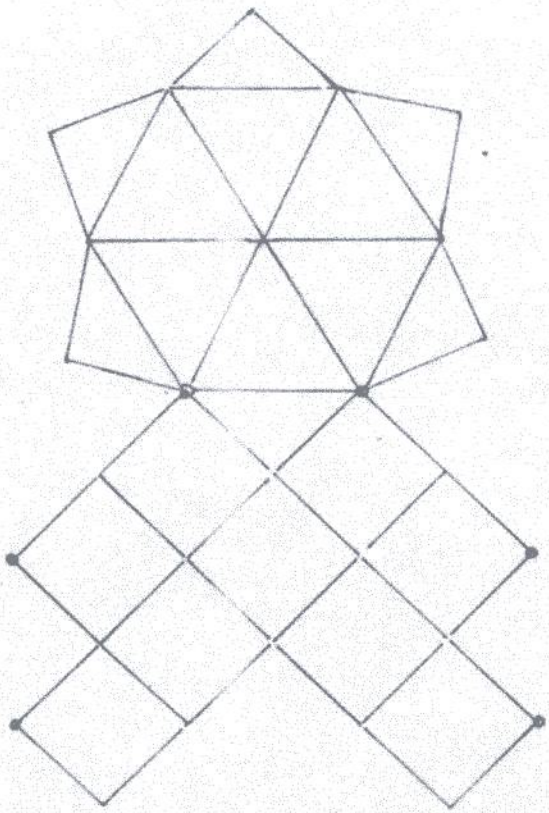
More help:

- Instead of trying to assemble the tetrahedron on the table, build it upside down in the clear plastic hopper.

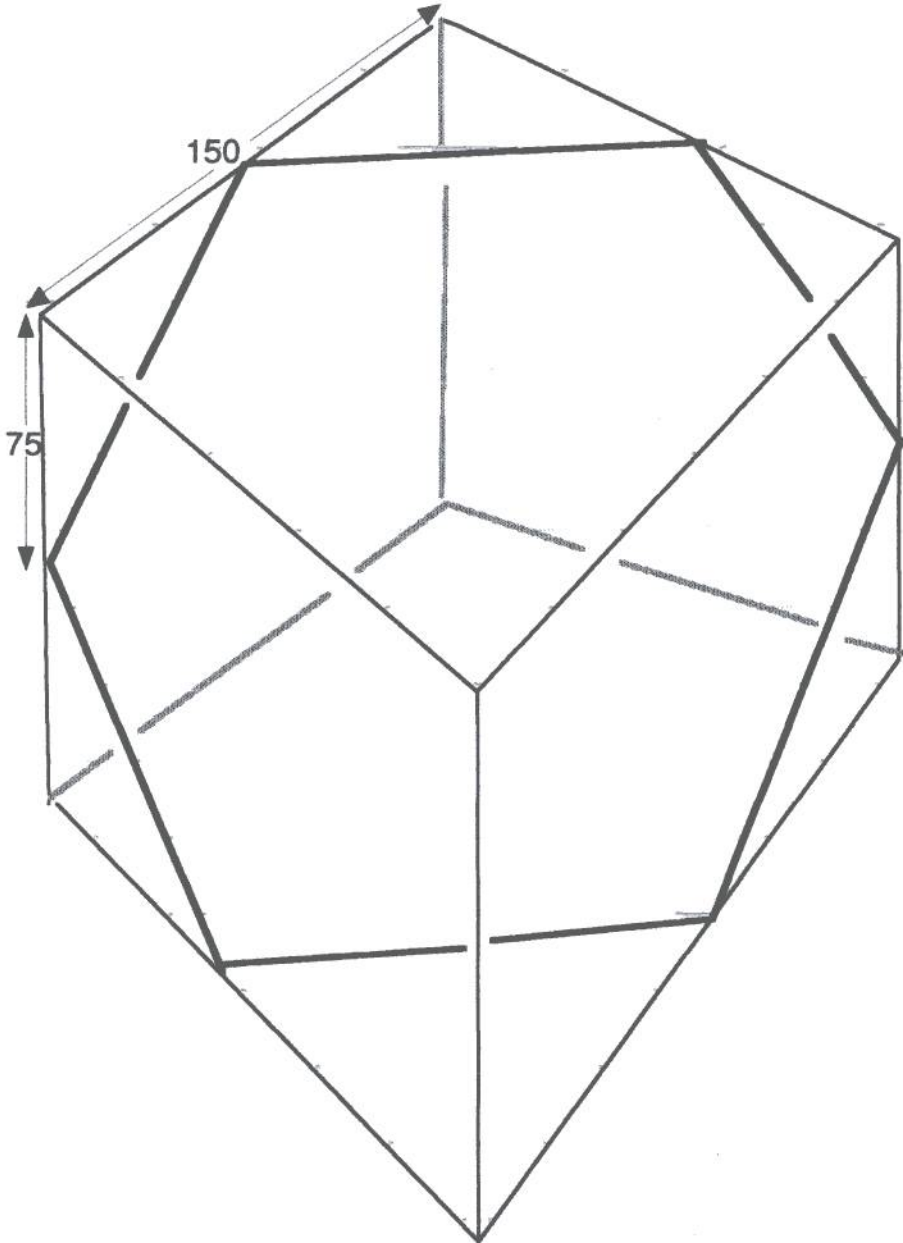
	NUMBER	TITLE
GROUP	3	SYMMETRY
STATION	3.7.3	THE 2-PIECE CUBE
TOPIC		(Extension Activity)

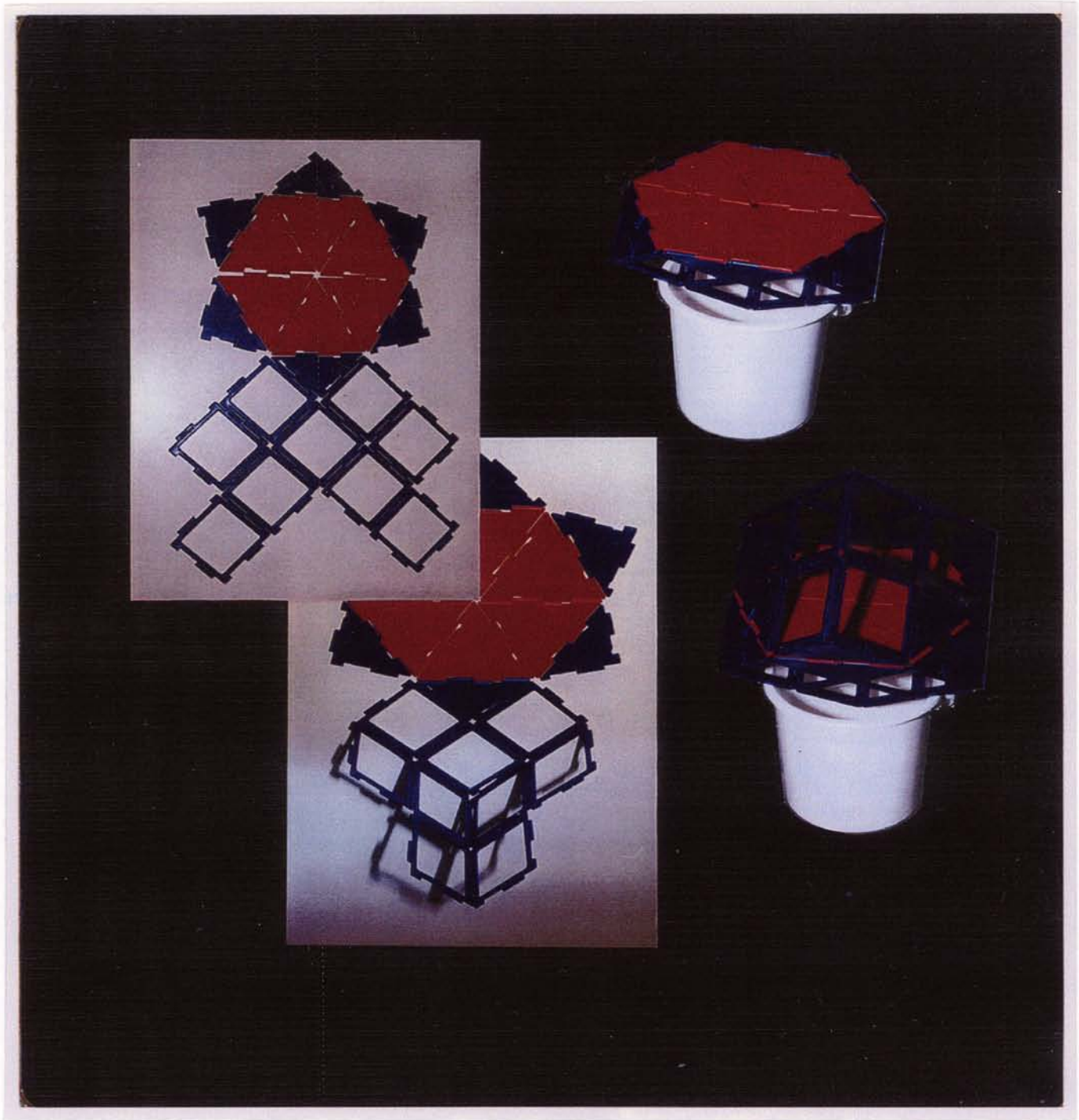
THE 2-PIECE CUBE

- **Set the perspex model in the black box and section it with light along the red line to show the HEXAGON.**
- **Use Polydron to build the 2 identical pieces of a puzzle. Here is the net for each:**

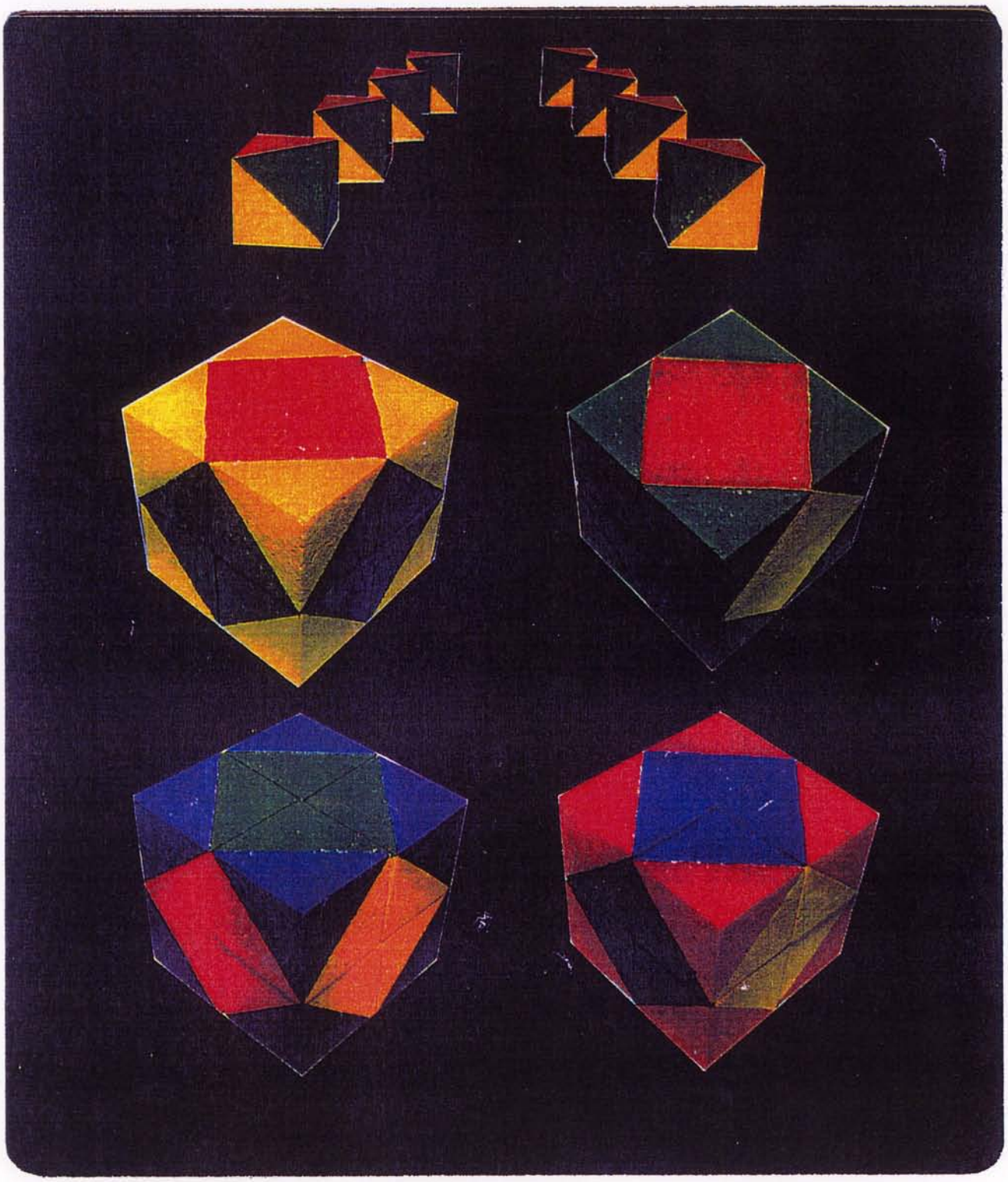


3.7.3





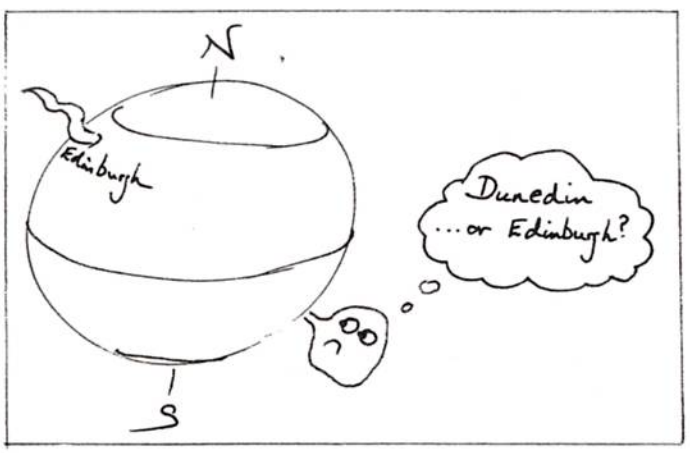
3.7.4



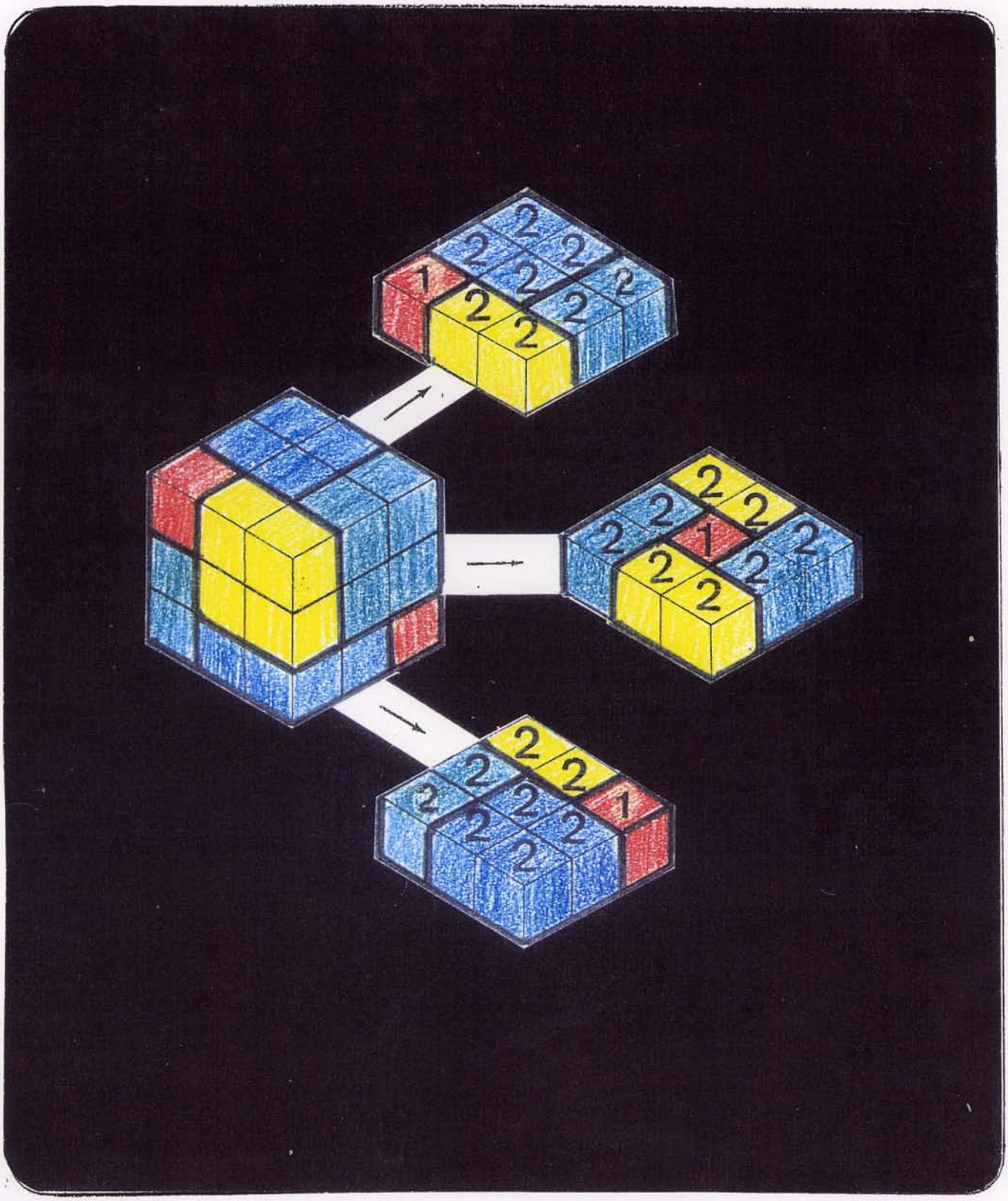
THE ANTIPODEAN CUBE

▶ This cube has CENTRAL symmetry.

A worm boring its way straight through the centre comes out where it started
—or that's what he thinks !



▶ P.T.O. for an exploded view. ▶



THE RHOMBIC STAR

- Make 2 mirror halves,
  each of 3 pieces.
  The apices (top points) of their 3
  pyramids meet.

- Hold one half in your left hand,
  one in your right,
  the imaginary mirror between them.

  An axis of 3-fold rotation
  symmetry runs from one hand
  to the other.

- Give one hand a 60° twist
  about this axis.

- Bring your hands together.

- To undo the star,
  stand it on 3 points.
  (When you look down on it, you
  will see a 6 -pointed star.)
  Take the 3 uppermost points in
  one hand, the 3 points on the table
  in the other.

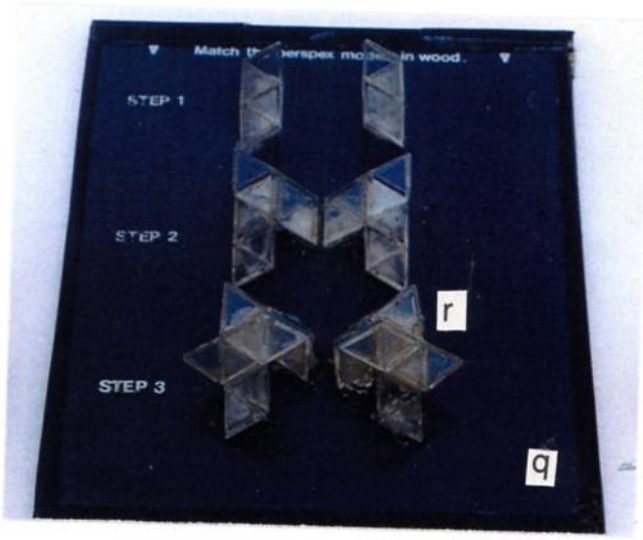
- Draw your hands apart.

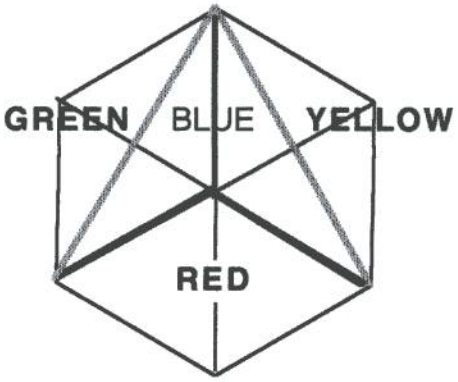
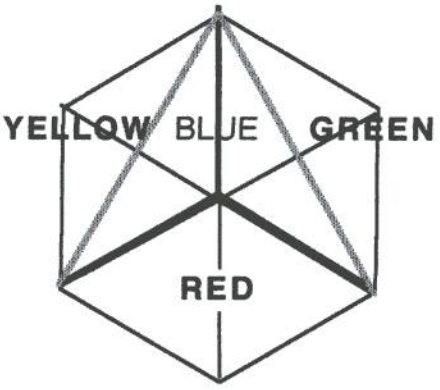
“Match the perspex models in wood.”

“STEP 1”

“STEP 2”

“STEP 3”



PICTURE KEY	DESCRIPTION	TRADE NAME	U.K. SOURCE
3.7.1 p	segments as shown made from 10 mm cubes*	Centicube	(see **1.8**)
3.7.2	as product: * The name '**2** - Piece Tetrahedron' derives from the familiar Christmas cracker puzzle where the 3rd piece is shared between the others.	The Pyramid Puzzle	ThinkFun 1321 Cameron St Alexandria, VA 22314 USA T/F: + 1-703-549-4999/6210 E: support@thinkfun.com W: www.binaryarts.com
3.7.3	expanded polystyrene, case-hardened with PVA		local
3.7.4	8 wooden cubes, 25 mm, painted as shown on caption and below, in 2 chiral groups of 4:   		local
3.7.5	wooden cubes, 40 mm, assembled and painted as shown on caption and described here: 3 single cubes, red 3 x 2 square prisms, each of 4 cubes in the colours: blue, green, yellow		local

PICTURE KEY	DESCRIPTION	TRADE NAME	U.K. SOURCE
3.7.6	3, as product: 1 for the puzzle itself, 2 to be used as below.	The Rhombic Star	Pentangle Salisbury Lane Over Wallop Stockbridge Hampshire SO20 8HT T/F: 01264 781833/782223 W: www.pentangle-puzzles.co.uk
3.7.6 q	caption board as described, art work as shown		
3.7.6 r	segments stuck to **q** as illustrated* to show the 3 stages of assembly of the 2 halves *In the version shown, these are in perspex. If the wooden version is used, the caption should be amended as follows: "Match each step in assembling *your* model with that shown on the board."		

	NUMBER	TITLE
GROUP	3	SYMMETRY
STATION	3.8	TILES IN CUTOUTS
TOPIC		Mirror and rotation symmetry

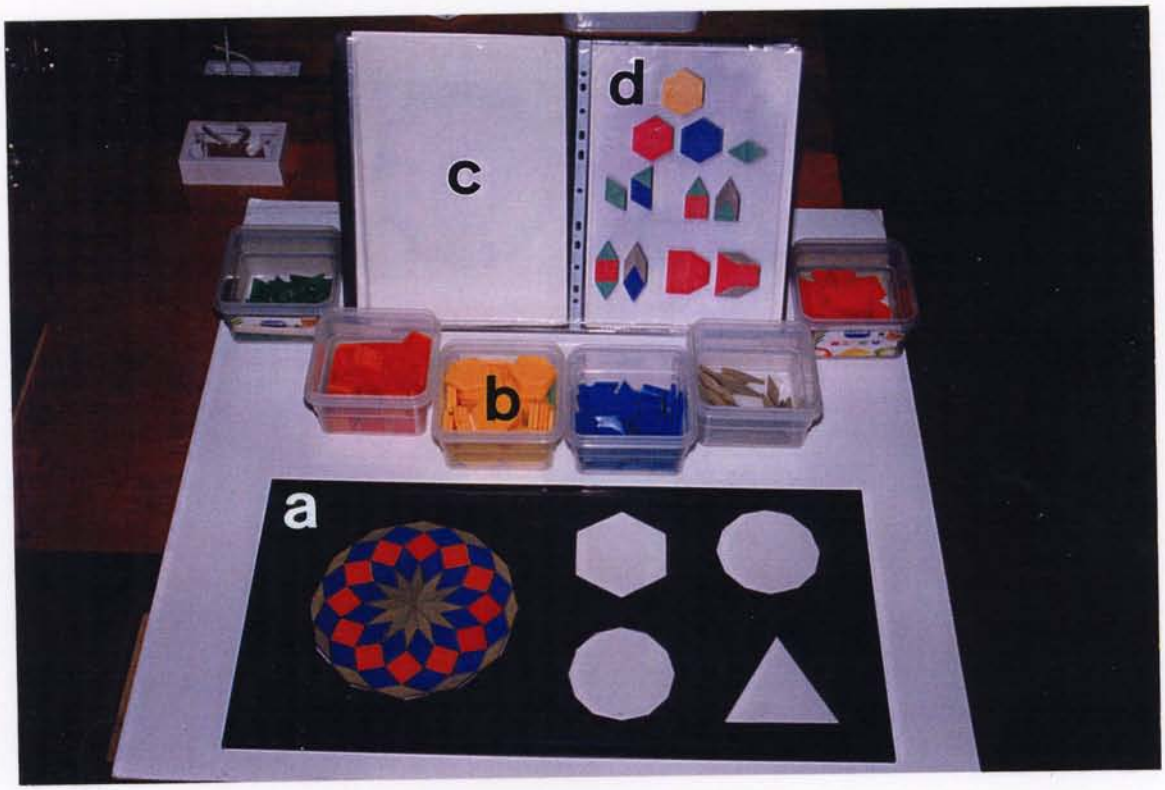
TILES IN CUTOUTS

- **Make your own designs.**
- **Give them SYMMETRY:**

▶ **MIRROR SYMMETRY ALONE.**

▶ **MIRROR SYMMETRY AND ROTATION SYMMETRY.**

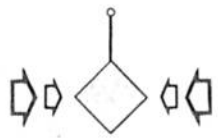
▶ **ROTATION SYMMETRY ALONE.**


c
d
b
a

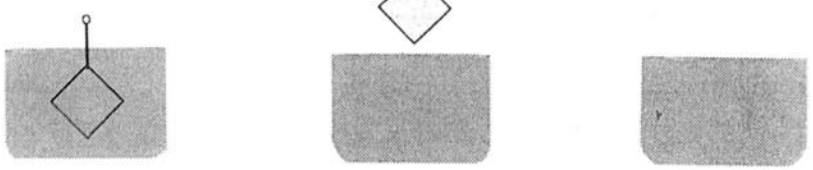
PICTURE KEY	DESCRIPTION	TRADE NAME	U.K. SOURCE
a	PVC, 3 mm, 500 mm x 300 mm, regular polygons cut out as shown, edge length to match **b**, backed with Glodex sheet	Amari Foam, 3 mm	Amari Plastics (address above)
b	set of polygonal tiles, whose angles are multiples of 15°	Pattern blocks	
		NES Arnold catalogue: BB 8348/5	NES Arnold Ltd (address above)
c	display book of patterns taken from the Magic Mathworks **DISSECTIONS** file: younger children can lay these under **a** and match them directly with **b**		The Magic Mathworks (address above)
d	a page of equivalences in **c**, suggesting substitutions one can make		

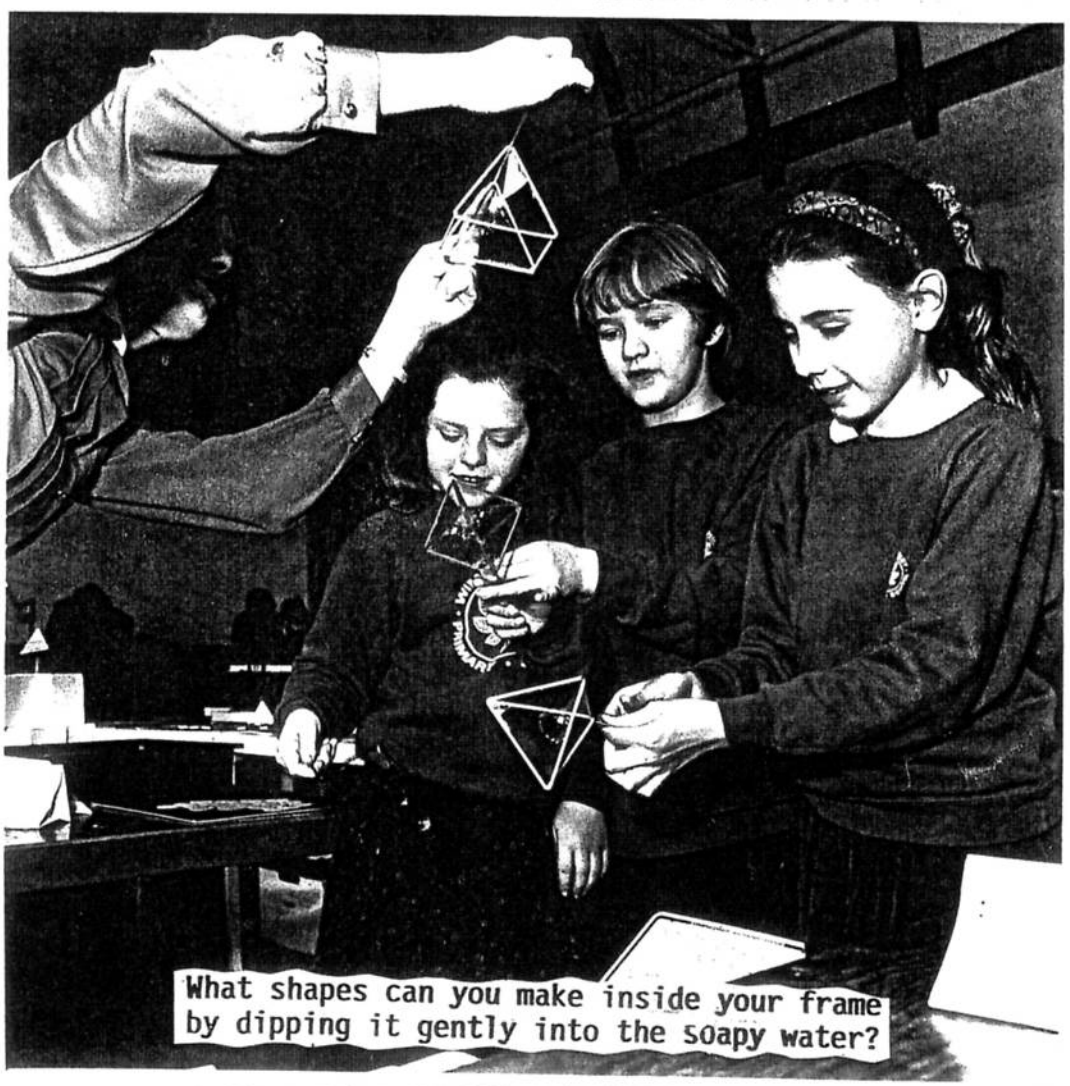
	NUMBER	TITLE
GROUP	3	SYMMETRY
STATION	3.9.1	SOAP FILMS
TOPIC		The symmetry of minimal surfaces

SOAP FILMS



- Dip gently in ... Lift gently out ... Look ...

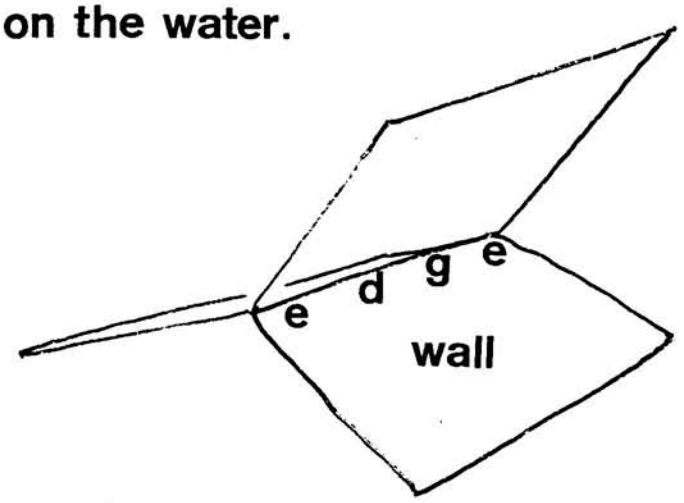




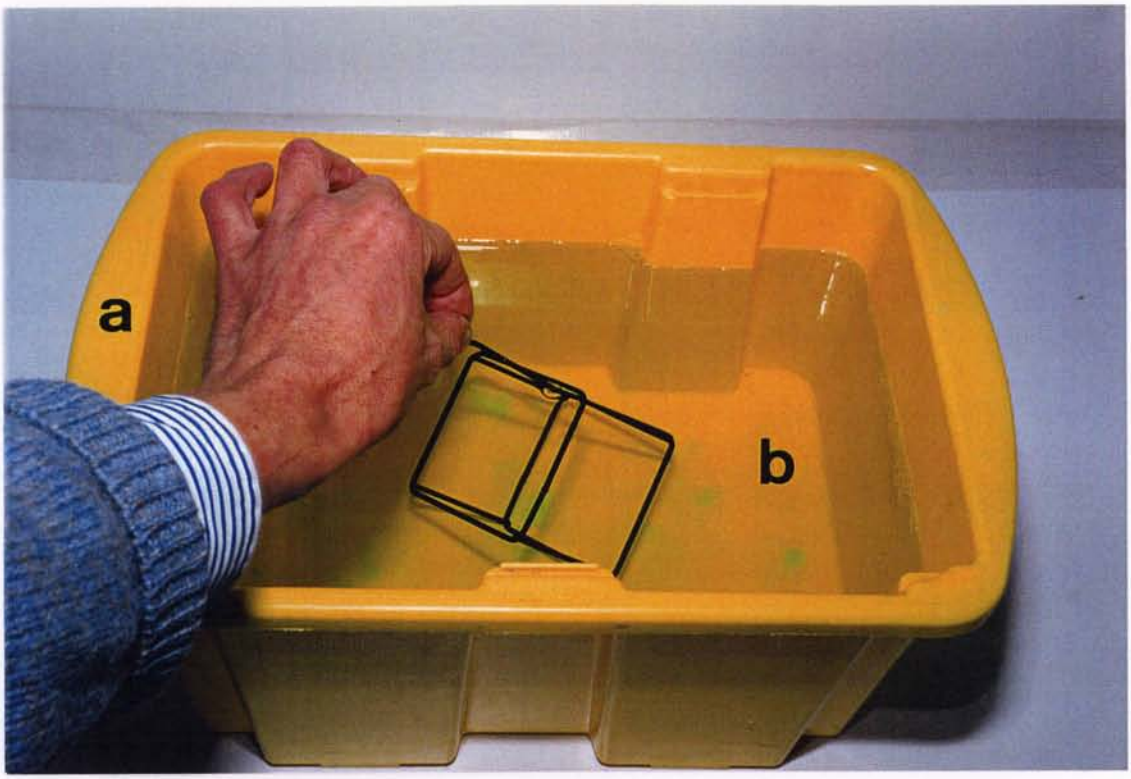
	NUMBER	TITLE
GROUP		
STATION		(Above continued)
TOPIC		

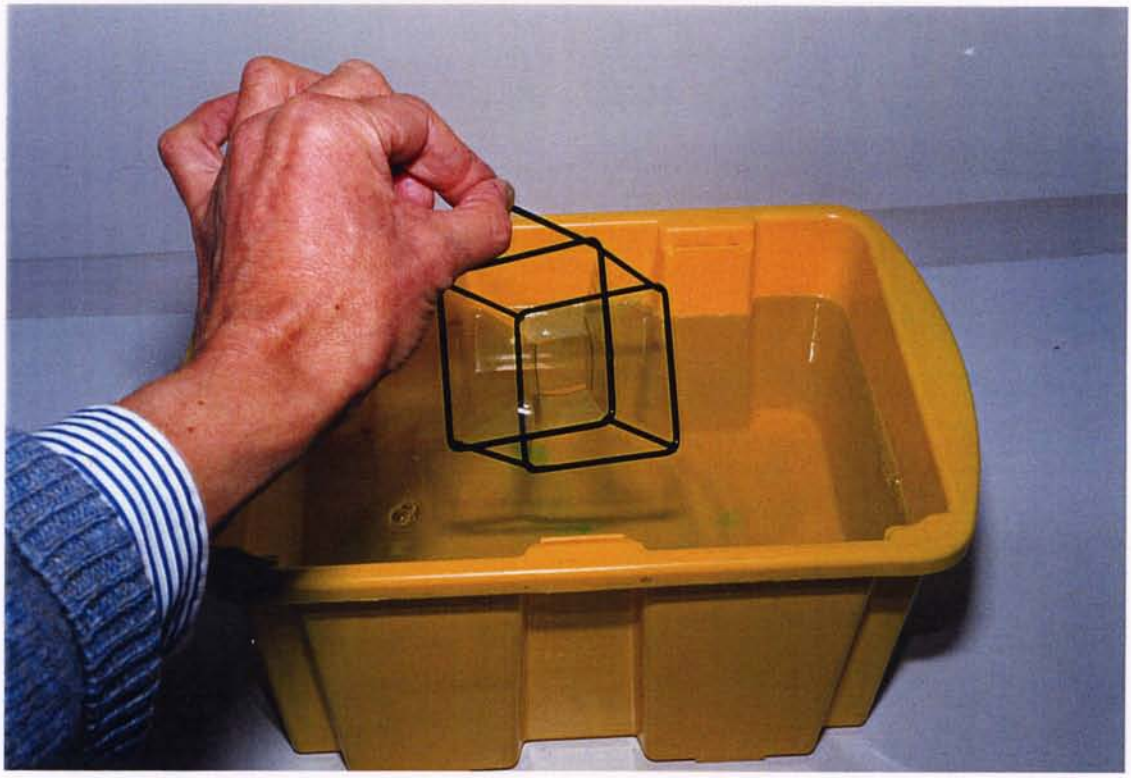
▶ **Ways to change what you've got:**

- **Pop a wall with a dry finger.**
- **Blow gently along an edge.**
- **To trap a bubble:**
  Touch your frame on the water.
  Lift off.



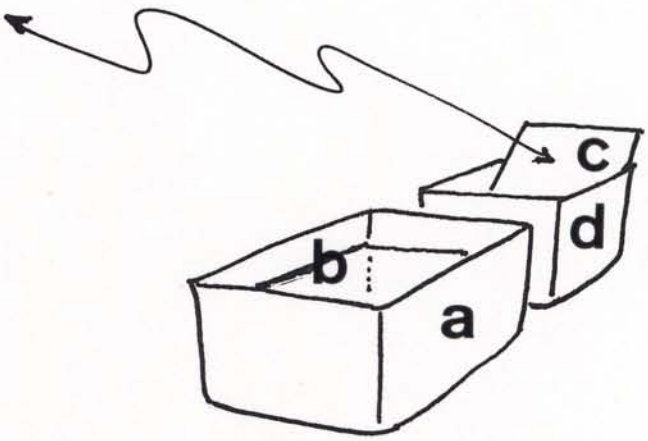
- **Sweep foam from the water with the FROTH SCOOP.**


a
b

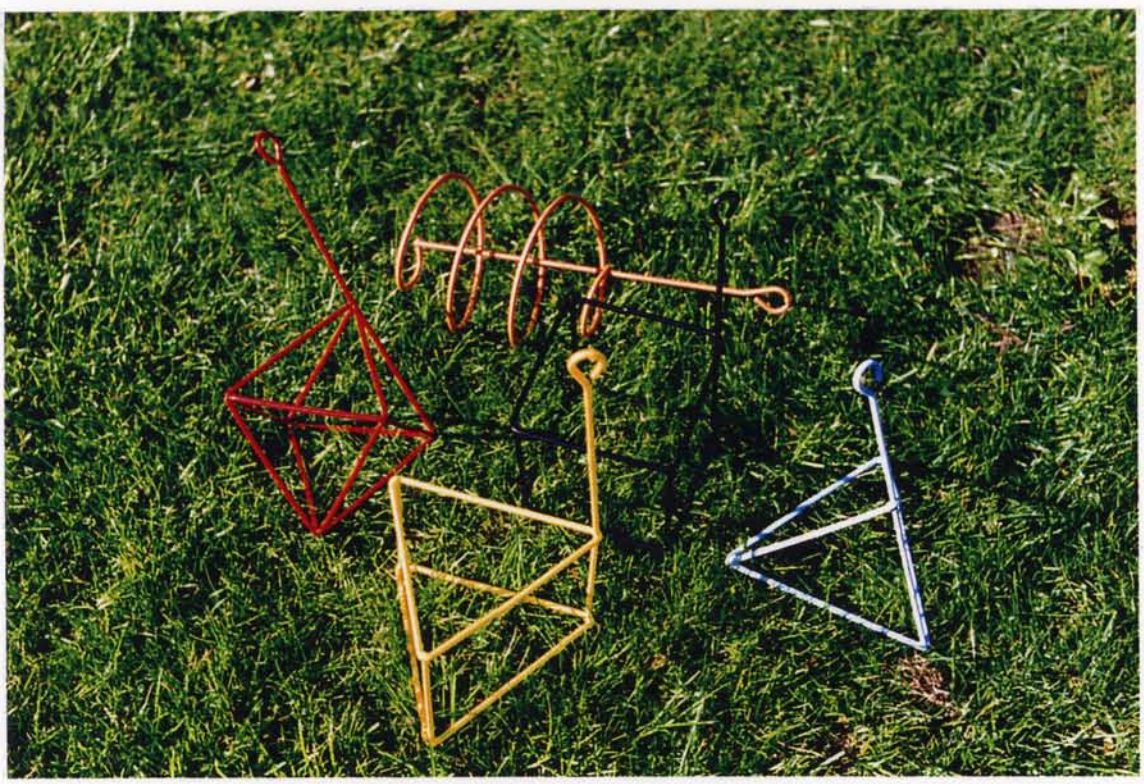


c

FROTH SCOOP



e

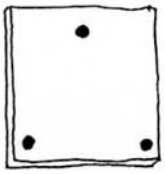


	NUMBER	TITLE
GROUP	3	SYMMETRY
STATION	3.9.2	MOTORWAY NETWORKS
TOPIC		As 3.9.1

MOTORWAY NETWORKS

▶ DRY AREA

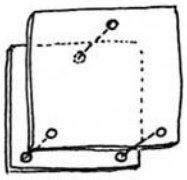
- ▶ This is for your *predictions.*
- ▶ Here you find boards like this:



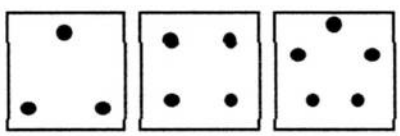
- ▶ The spots are cities.
- ● Take a dri-wipe pen and join up the cities with what you think is the shortest total length of motorway.

▶ WET AREA

- ▶ This is for your *experiments.*
- ▶ Here you find models like this:



- ▶ The bolts are cities.
- ● Dip the perspex model into the soapy water and draw it slowly out.
- ■ Does the soap film make your shape?

PICTURE KEY	DESCRIPTION	TRADE NAME	U.K. SOURCE
a	any container, rectangular in plan, which can accommodate a water depth > 120 mm (the space *diagonal of the skeleton cube in* **e**)		local
b	water with detergent, strength not critical - say 3-4 times what one would use for washing up		local
c	plasticard sheet, marked as shown, width slightly less than that of **a**		local
d	receptacle for **c**, into which one can sweep foam, of same width as **a**		local
e	The set of plastic-coated wire frames shown are no longer available*. Substitute the equivalent demountable kit, using plastic straws and vertex connectors:	Kubic Bubbles	Cochranes of Oxford Ltd Fairspear House Leafield Widney Oxon OX29 9NY T/F: +44 1993 878641/416 E: cochranes@mailbox.co.uk W: www.cochranes.co.uk
f-h	caption board as described, artwork as below, faced with Glodex:  **f** **g** **h**		local
i-k	corresponding models: in the Kubic Bubbles kit each is made by setting moveable rubber spacers in the correct positions between the parallel perspex plates * - except from the designer**	Kubic Bubbles	** Dr Cyril Isenberg Department of Physics University of Kent Canterbury Kent CT2 7NR T: +44 1227 764000 ext. 3768 F: +44 1227 475423
	If you require a kit which *cannot* be dismantled, use this, (also designed by Dr Isenberg) modifying the dimensions of **a-e** accordingly:	Improba-bubbles	Beevers Miniature Models Unit Department of Chemistry University of edinburgh West Mains Road Edinburgh EH9 3JJ T/F: +44 131 650 4824/4743 E: bmmu@ed.ac.uk