KETTLE'S YARD

Beyond Measure
conversations in art and science

5 April – 1 June 2008

Teachers' Pack

- Introduction
- Lines of questioning and activities (KS1 & 2)
- Lines of questioning and activities (KS3 & 4)
- Key ideas
- List of contributors
- Activity sheets from the gallery

Introduction to Beyond Measure

‘Geometry’ often brings to mind circles, squares and triangles but it is so much more than that. The word itself means ‘measuring the Earth’ (geo = earth, metrics = to measure). Taken in its broadest sense, geometry had numerous applications, ranging from designing the London Underground Tube map to plotting skin grafts to exploring the structure of atoms to making artwork.

This exhibition includes 60 contributors who all use geometry as part of their practice. The selection of contributors places particular emphasis on the worlds of science and the arts, two fields that may at first glance seem to have little in common but are both driven by creativity, curiosity and the visualisation of abstract ideas.

The most primitive means of measuring one’s environment is the human body. Measuring the height of horses by ‘hands’ or pacing out the length of a room are two examples of how we measure space against our own proportions. The Roman architect Vitruvius took this principle even further. His famous treatise ‘On Architecture’ was a guide for buildings as well as town planning and he also included descriptions of ideal human proportions, making a direct connection between the shape of us and the shape of spaces we live in. His idea was the inspiration for Leonardo da Vinci’s *Vitruvian Man*, *1492*, the idealised male body within a circle and a square.

How we relate to the size of a house or the distance between towns or the girth of the planet all comes back to the proportions of the human body. We marvel at how BIG the universe is as astronomers reach further and further into space and are equally impressed by how SMALL protons and neutrons are within atoms, just to be told that they are made by something even smaller again – quarks! Artists have often manipulated scale to elicit a response from the viewer. David Nash’s *Wooden Boulder, 1978-present,* documented in the show by photographs, is impressive not least because, relative to a person, it is very large.

A recurring theme in the show is the division between a phenomenological space (what we actually see and experience) and an idealised space (the worlds of ideas, thoughts and theories). For example, we can see and directly experience three-dimensional space however new theories on subatomic structures suggest there may be as many as 26 dimensions. Similarly, Plato argued that the ideal, perfect circle can never be experienced and therefore exists in another realm of ideas. Langlands and Bell have two artworks in the show that explore this dichotomy: *Air Routes of Britain (Day), 2000* and *Air Routes of Britain (Night), 2000.* Without the titles, the lines and dots appear as abstract patterns. With the titles, we can suddenly read the image as a map and interpret the lines as air routes, an event that actually happens (planes fly over Britain) but that looks very different from how it has been represented (dots and lines).

The exhibition also blurs the distinction between objects created by scientists and objects created by artists. A clear example is the crocheted hyperbolic planes, made by Dr Daina Taimina as a teaching aid for her mathematics students at Cornell University, New York, and the ceramic sculptures by Swedish artist Eva Hild. The objects are very similar in shape, exploring the fluctuations between interior and exterior surfaces, but originate from different thought processes.

Taimina explains her work as follows: “For exploring different forms of the hyperbolic plane, I start with a shape I call the symmetric hyperbolic plane. I make this form following a mathematically calculated pattern in which the number of stitches in each row increases exponentially; that ensures the resulting surface has constant negative curvature (a necessary requirement for the hyperbolic plane). In two dimensions there are three geometries possible – plane geometry (no curvature), spherical geometry (constant positive curvature) and hyperbolic geometry. Once the basic shape is finished, the fun part of sculpting can start.”

In comparison, Hild describes her sculptures as follows: “Delicate continuously flowing entities in thin white-built clay. They reflect varying degrees of external and internal pressures and how, as a consequence, perception of inner and outer space is changed or challenged. My inspiration is the ever-changing landscape of my own life and environment! I try to relate my work to my life. What is happening and how does it feel?”

The distinction between mathematician and artist also isn’t clear-cut. Taimina is not just using crochet to describe geometry, she is making a number of aesthetic and subjective choices, such as the colour of the thread and the overall look of her work. Hild meanwhile is not consciously making hyperbolic planes but she is employing her skilled understanding of the clay to engineer these structures that have to support their own weight.

A final theme for consideration is the gallery itself. The exhibition draws parallels between the working spaces of a range of disciplines, whether it is an artist’s studio, a laboratory, a study or an observatory. In each, people are developing ideas through a process of experimentation. Rarely are ideas born fully formed; most undergo a process of refinement, improvement and adaptation.

We have an education table for the public in one of the gallery spaces with a number of practical activities. The activity sheets have been included in this pack and I would prefer that your class used these activities at school, rather than in the gallery. Thank you.

Lines of questioning for KS1 & 2

- Why do we have art galleries? What do they do?
- From where you are standing/sitting, which objects do you think are art and which objects are not art? How have you made those decisions?
- Would you expect to see any of these objects somewhere else (an office or a laboratory)?
- What is the function of these objects?
- Could the same object be art in a gallery and not-art outside a gallery?
- Is everything in an art gallery called art? Why or why not?
- What are the differences between a circle and a sphere, a square and a cube or a triangle and a cone?
- Why is it useful to measure things (whether it is the length of a caterpillar or the distance to Hull)?
- Why do we all need to agree on the length of a centimetre?

Activities

- Origami is ideal for combining geometrical shapes to make small 3D sculptures. Check cheap bookshops or the web for patterns.
- Using a tape measure and working in small groups, map the proportions of the human body (length of hip to knee, then knee to heel, then heel to toe, etc). Draw to scale on large roll of paper. Use colour symbolically, so all lengths under 10cm are green, all lengths 11-50cm are red, etc. Discuss how this 'map' of a person differs from an actual person.
- Find alternative ways of mapping the journey from home to school (road map? photographs? key words? sketches? spoken description?).
- There are many examples of geometrical patterns in the natural world. Take inspiration from snowflakes, tree barks, ferns, pinecones, pineapples, or cloud formations to make abstract geometrical patterns on graph paper. These patterns could then be transferred into a block print and repeated.

Lines of questioning for KS3 & 4

- Looking around the gallery, how easy is it to distinguish the artworks from the other objects? What criteria do you use to separate them?
- What is art? What is science? What do they have in common?
- Compare one artwork with one ‘non-artwork’ that looks similar. Are the ideas behind each object similar as well (ie. were the people who made them thinking about the same sorts of ideas)?
- Some of the objects represent abstract ideas, some of the objects represent observable phenomena. Find examples of both.
- What impact does scale have on your experience of these works? If an object is considered ‘big’, what is that in relation to?
- Why is it important to have centimetres, litres, tonnes, etc? Why is it useful to have an agreed measurement for distances great and small?

Activities

- Peter Peri is an artist who uses the visual language of molecular biology to influence his abstract paintings (the lines and circles are reminiscent of something you would view down a microscope). Taking Peri as inspiration, source highly magnified imagery and then translate these forms and textures into an abstract composition.
- Sarah Morris is a painter who creates geometric interpretations of cityscapes. Sketch a scene from your environment (bedroom, view from window, schoolground, etc) and then convert this scene to a strict series of geometric shapes that still retains a sense of the original scene.
- Allies and Morrison are the architects who designed the Peter Harrison Planetarium at Greenwich. The use of the building is echoed in its shape: “The cone has been sliced to produce an elliptical face, mirrored to reflect the passing sky. It transpires that the inscribed angle of the inclined face is 51.5º, corresponding to the latitude of Greenwich. The conic section is made at 90º to this face, which means that the mirrored plane is parallel to the Equator. The vertical edge designates the zenith, while an inscribed line running up the sloping contour acts as a sighting line for the North Star”. Design a customised building (be it a doghouse or a swimming pool or cinema) where the shape of the building reflects its function.

Key ideas

There may be some phrases or ideas in the show that are new to you (they were new to me!) so I have compiled a crib sheet to help. As you will see, I have sourced a lot of this information from Wikipedia, which has a lot of fantastic diagrams and images that will also help.

As the descriptions are not listed in alphabetical order (one thought seems to follow the other) I have provided a table of contents below:

Euclidean and Non-Euclidean Geometry

A mathematical system attributed to the Greek mathematician Euclid of Alexandria (c.300BC). Euclid's text Elements is the earliest known systematic discussion of geometry. Although many of Euclid's results had been stated by earlier Greek mathematicians, Euclid was the first to show how these propositions could be fit together into a comprehensive deductive and logical system.

The Elements begin with plane geometry, still taught in secondary school as the first axiomatic system. The Elements goes on to the solid geometry of three dimensions, and Euclidean geometry was subsequently extended to any finite number of dimensions.

For over two thousand years, the adjective "Euclidean" was unnecessary because no other sort of geometry had been conceived. Euclid's axioms seemed so intuitively obvious that any theorem proved from them was deemed true in an absolute sense. Today, however, many other self-consistent non-Euclidean geometries are known, the first ones having been discovered in the early 19th century. It also is no longer taken for granted that Euclidean geometry describes physical space. An implication of Einstein's theory of general relativity is that Euclidean geometry is only a good approximation to the properties of physical space if the gravitational field is not too strong. *(http://en.wikipedia.org/wiki/Euclidean_geometry)*

General Relativity

General relativity (GR) is a theory of gravitation that was developed by Albert Einstein between 1907 and 1915. According to general relativity, the observed gravitational attraction between masses results from those masses warping nearby space and time. Previously, Newton's law of universal gravitation (1686) had described gravity as a force between masses, but experiments have shown that Einstein's description is more accurate. What is more, general relativity predicts interesting new phenomena such as gravitational waves.

General relativity accounts for several effects that are unexplained by Newton's law, such as minute anomalies in the orbits of Mercury and other planets, and it makes numerous predictions – since confirmed – for novel effects of gravity, such as the bending of light and the slowing of time. Although general relativity is not the only relativistic theory of gravity, it is the simplest such theory that is consistent with the experimental data. However, a number of open questions remain: the most fundamental is how general relativity can be reconciled with the laws of quantum physics to produce a complete and self-consistent theory of quantum gravity.

The theory has developed into an essential tool for modern astrophysics. It provides the foundation for our current understanding of black holes; these are regions of space where gravitational attraction is so strong that not even light can escape. Their strong gravity is thought to be responsible for the intense radiation emitted by certain types of astronomical objects (such as active galactic nuclei or microquasars).
(http://en.wikipedia.org/wiki/Introduction_to_general_relativity)

Quantum physics/mechanics

Quantum mechanics (QM, or quantum theory) is a physical science dealing with the behaviour of matter and energy on the scale of atoms and subatomic particles/waves. QM also forms the basis for the contemporary understanding of how very large objects such as stars and galaxies, and cosmological events such as the Big Bang, can be analyzed and explained. Quantum mechanics is the foundation of several related disciplines including nanotechnology, condensed matter physics, quantum chemistry, structural biology, particle physics, and electronics.

The term "quantum mechanics" was first coined by Max Born in 1924. The acceptance by the general physics community of quantum mechanics is due to its accurate prediction of the physical behaviour of systems, including systems where Newtonian mechanics fails. Even general relativity is limited—in ways quantum mechanics is not—in describing systems at the atomic scale or smaller, at very low or very high energies, or at the lowest temperatures. Through a century of experimentation and applied science, quantum mechanical theory has proven to be very successful and practical.
(http://en.wikipedia.org/wiki/Introduction_to_quantum_mechanics)

Fibonacci sequence

Leonardo of Pisa, known as Fibonacci, was a medieval Italian mathematician who wrote *Liber abaci* (1202; "Book of the Abacus"), the first European work on Indian and Arabian mathematics. His name is known to modern mathematicians mainly because of the Fibonacci sequence derived from a problem in the *Liber abaci*:

A certain man put a pair of rabbits in a place surrounded on all sides by a wall. How many pairs of rabbits can be produced from that pair in a year if it is supposed that every month each pair begets a new pair which from the second month on becomes productive?

The resulting number sequence, 1, 1, 2, 3, 5, 8, 13, 21, 34, 55 (Leonardo himself omitted the first term), in which each number is the sum of the two preceding numbers, is the first recursive number sequence (in which the relation between two or more successive terms can be expressed by a formula) known in Europe. The mathematician Robert Simson at the University of Glasgow in 1753 noted that, as the numbers increased in magnitude, the ratio between succeeding numbers approached the number a, the golden ratio, whose value is 1.6180 . . . , or (1 + Ö5)/2.

In the 19th century the term Fibonacci sequence was coined by the French mathematician Edouard Lucas, and scientists began to discover such sequences in nature; for example, in the spirals of sunflower heads, in pine cones, in the regular descent (genealogy) of the male bee, in the related logarithmic (equiangular) spiral in snail shells, in the arrangement of leaf buds on a stem, and in animal horns. *(www.britannica.com/eb/article-4153/Leonardo-Pisano)*

Fractals

A fractal is generally "a rough or fragmented geometric shape that can be subdivided into parts, each of which is (at least approximately) a reduced-size copy of the whole," a property called self-similarity. The term was coined by Benoît Mandelbrot in 1975 and was derived from the Latin fractus meaning "broken" or "fractured."

A fractal often has the following features:

- It has a fine structure at arbitrarily small scales.
- It is too irregular to be easily described in traditional Euclidean geometric language.
- It is self-similar (at least approximately or stochastically).
- It has a Hausdorff dimension which is greater than its topological dimension (although this requirement is not met by space-filling curves such as the Hilbert curve).
- It has a simple and recursive definition.

Because they appear similar at all levels of magnification, fractals are often considered to be infinitely complex (in informal terms). Natural objects that approximate fractals to a degree include clouds, mountain ranges, lightning bolts, coastlines, and snow flakes. However, not all self-similar objects are fractals—for example, the real line (a straight Euclidean line) is formally self-similar but fails to have other fractal characteristics.
(http://en.wikipedia.org/wiki/Fractal)

Platonic solids

In geometry, a Platonic solid is a convex regular polyhedron.

The Platonic solids feature prominently in the philosophy of Plato for whom they are named. Plato wrote about them in the dialogue Timaeus c.360 B.C. in which he associated each of the four classical elements (earth, air, water, and fire) with a regular solid. Earth was associated with the **cube**, air with the **octahedron**, water with the **icosahedron**, and fire with the **tetrahedron**. There was intuitive justification for these associations: the heat of fire feels sharp and stabbing (like little tetrahedra). Air is made of the octahedron; its minuscule components are so smooth that one can barely feel it. Water, the icosahedron, flows out of one's hand when picked up, as if it is made of tiny little balls. By contrast, a highly un-spherical solid, the hexahedron (cube) represents earth. These clumsy little solids cause dirt to crumble and break when picked up, in stark difference to the smooth flow of water. The fifth Platonic solid, the **dodecahedron**, Plato obscurely remarks, "...the god used for arranging the constellations on the whole heaven". Aristotle added a fifth element, aithêr (aether in Latin, "ether" in English) and postulated that the heavens were made of this element, but he had no interest in matching it with Plato's fifth solid. *(http://en.wikipedia.org/wiki/Platonic_solid)*

Penrose tiling

The original Penrose tiling was proposed by Roger Penrose in 1974 in a paper entitled 'The Role of Aesthetics in Pure and Applied Research'. Not more than one fifth of the paper deals with it but Penrose admits that the tiling was its real point.

Attempting to tile the plane with regular pentagons must necessarily leave gaps. Penrose found a particular tiling in which the gaps may be filled with three other shapes: a star, a boat and a diamond. In addition to the tiles, Penrose stated rules, usually called matching rules, that specify how tiles must be attached to one another; these rules are needed to ensure that the tilings are nonperiodic. As there are three distinct sets of matching rules for pentagonal tiles, it is common to consider the set as having three different pentagonal tiles. This leads to a set of six tiles: a thin rhombus or 'diamond', a five pointed star, a 'boat' (roughly 3/5 of a star) and three pentagons. Penrose later found two more sets of aperioidic tiles, one consisting of tiles known as a 'kite' and a 'dart' and a second set consisting of two rhombuses. *(http://en.wikipedia.org/wiki/Penrose_tiling)*

List of contributors

Mr Tariq Ahmad
Consultant plastic reconstruction and aesthetic surgeon
Addenbrookes Hospital, Cambridge

Nader Ahriman
Artist

Paul Appleton
Architect
Allies and Morrison

Dr Francis Archer
Structural engineer
ARUP

Dr Miguel de Beistegui
Philosopher
University of Warwick

Alan Bennett
Glass blower / scientific instrument designer / maker

Dr Jim Bennett
Historian
Director of the Museum of the History of Science, University of Oxford

Dr Christopher Bergemann
Quantum physicist
(formerly) Cavendish Laboratory, University of Cambridge

Prof. Sir Tom Blundell
Biochemist
Sir William Dunn Professor of Biochemistry and
Head of the Department of Biochemistry, University of Cambridge

Jeff Bryant
Computer illustrator
Wolfram Research

Dr Robin Catchpole
Astronomer
University of Cambridge

Dr Tony Crowther
Molecular biologist
MRC Laboratory of Molecular Biology, University of Cambrige

Krysten Cunningham
Artist

Richard Deacon
Sculptor

Tom Dixon
Designer
Creative Director at Artek
Teaches at the Royal College of Art

Dr Phil Gaskell
Physicist
University of Cambridge

Prof. Gerry Gilmore
Physicist
University of Cambridge

Guillermo Gregorio
Composer/musician
Purdue University

Dr Peter Grindrod
Planetary geologist
University College, London

Felix Gonzalez-Torres
Artist

Dr Simon Guest
Engineer
University of Cambridge

Richard Hamilton
Artist

Dr Karl Harrison
Chemist
University of Oxford

Dr Tim Herman
Director
MSOE Center for BioMolecular Modeling, Milwaukee School of Engineering

Helen Hignell
Department of Earth Sciences, University of Cambridge

Eva Hild
Artist

Prof. Martin Hyland
Mathematician
Head of Department and Professor in Mathematical Logic
University of Cambridge

Prof. Sir Aaron Klug
Molecular biologist
Nobel Laureate – Chemistry 1982, MRC Laboratory of Molecular Biology, University of Cambridge

Dr Kevin Knowles
Material scientist
University of Cambridge

Langlands and Bell
Artists

Steve Laurie
Collections Assistant
Mineralogy and Petrology, Sedgwick Museum of Earth Sciences
University of Cambridge

Bob Law
Artist

George Henry Longly
Artist

Dr Alan Mackay
Crystallographer
(formerly) Birkbeck College, London

Kenneth Martin
Artist

Josiah McElheny
Artist

Dr Allan McRobie
Engineer
University of Cambridge

Tatsuo Miyajima
Artist

Keith Moore
Archivist
Head of Library and Information Services, Royal Society, London

Robert Morris
Artist

Sarah Morris
Artist

Dr Alex Moulton
Engineer
Alex Moulton Bicycles

Joshua Nall
Museum Assistant
Whipple Museum of the History of Science
University of Cambridge

David Nash
Sculptor

Carsten Nicolai
Artist

Prof. John Parker
Plant scientist
Director, Botanic Gardens, University of Cambridge

Eric Parry
Architect
Eric Parry Architects

Prof. Sir Roger Penrose
Mathematical physicist
Emeritus Rouse Ball Professor of Mathematics
University of Oxford

Peter Peri
Artist

John Pickering
Artist

Dr Richard Preece
Malacologist
Watson Curator of Malacology, University Museum of Zoology
University of Cambridge

Dr Gareth Rees
Natural scientist
Scott Polar Research Institute, University of Cambridge

Prof. Simon Schaffer
Historian
Department of the History and Philosophy of Science
University of Cambridge

Shoji Sadao
Architect

David Saunders
Fashion designer
DavidDavid

Conrad Shawcross
Artist

Dr Daina Taimina
Mathematician
Cornell University, New York

Keith Tyson
Artist

Dr Piers Vitebsky
Head of Anthropology and Russian Northern Studies
Scott Polar Research Institute, University of Cambridge

Dr Tennie Videler
Chemist
University of Cambridge

Jane Wess
Curator of mathematics
Science Museum, London

Father Magnus Wenninger
Mathematician and monk
St John’s Abbey, Collegeville, MN

Hugh Whitehead
Project Director, and his team
Specialist Modelling Group, Foster + Partners