A Synthesis of Sectors

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Abstract

This workshop presents a form of modular origami in which paper circles are folded, assembled and glued together to form a chain. By using circles of gradually varying diameter, one can form an ammonite-like spiral or an attractive wearable garland. Creating and manipulating the aesthetic forms in the workshop provides participants with opportunities for investigation and discussion of numerous mathematical and STEM concepts, simultaneously reinforcing the value of art and design in trans-disciplinary knowledge building (STEAM). Folding is a great source for numerous nontrivial connections to be made between mathematics, engineering, art and design. The act of folding offers moments of contemplation and meditation through the challenge and joy of making.

Introduction

When Japanese astrophysicist Koryo Miura proposed a folding method called 'miura-ori' in the design for Japan's 1985 satellite, the 'Space Flyer Unit', he inspired a myriad of unique folding developments with applications in a variety of industries. Miura's folding technique is rooted in tradition and history. The Miura fold is an element of the ancient Japanese tradition of origami and the practical application of map folding. Writer and developer Adam Pash describes the Miura-ori fold as pretty, like origami and useful like a fox [13]. And surprisingly, the characteristic zig-zags can also be seen in the portrait of the Italian aristocrat Lucrezia Panchiatichi, painted in 1535 by Agnolo Bronzino. In a similar vein, *A Synthesis of Sectors* (SoS) workshop encompasses a number of concepts and folding techniques found in the vast world of origami, including collapsible origami [16], modular origami, map folding, fashion design and biomimicry. More specifically, the workshop artifacts are made up of sets of folded circles cut from paper maps. We refer to the Miura fold in the context of "pop-out", sometimes known as the Turkish Map Fold. Traditionally, this map fold is constructed from a square or rectangular base using inclined folding lines [1], an essential element of a traditional Miura fold. Our point of difference, is that we replace rectangles with circles, referencing the 2006 research of psychologists Bar and Neta, who found that on average, people prefer curves [3]. We combine the math inherent in paper map folding with the image of maps as ornament, adding a visual aesthetic to the outcome of our making (Figure 1).

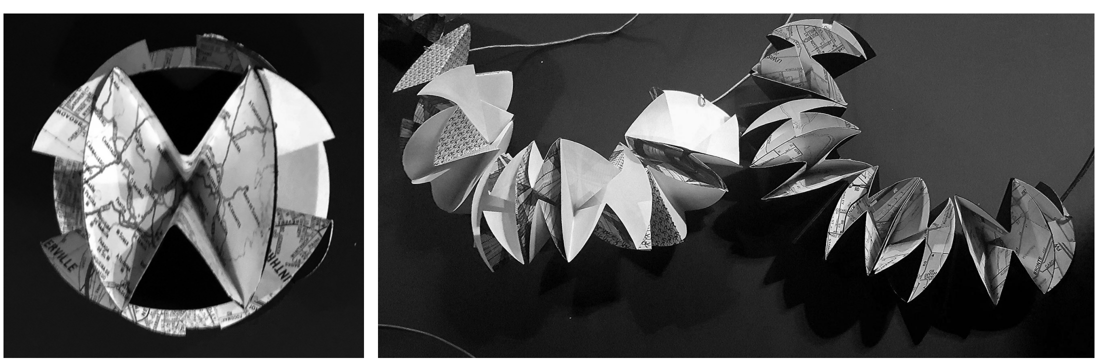


Figure 1: *Miura folded wearables with map surface - Sydney Craft Week 2018.*

Background

Curves are, by their very nature, easy on the eye. "People dig curves" and prefer them over sharp angles [4]. The implications of such human responses influenced the aesthetic elements related to the development of the SoS workshop. Paper artist Lisa Giles [6] joined forces with Annette Mauer and Melissa Silk from STEAMpop [15] to develop the ideas and techniques underpinning the SoS workshop. Lisa has folded origami structures for more than 10 years, drawn to investigating how origami influences the design of artist's books while completing her Master of Arts study. Like most people, Lisa started folding square papers, generally considered the basis of traditional origami structures (Figure 2). During her explorations, Lisa stumbled upon 'Whatman' scientific papers and gained access to circular papers in many sizes. Concurrently, Annette and Melissa were developing projects related to origami sekkei, creating beautiful paper objects and delivering professional development to teachers, students and the general public, Australia wide. The first iteration of the SoS project was delivered at Sydney Craft Week in 2018, in which participants created wearable pieces using paper map circles of equal sizes (Figure 1). This experience inspired the newly formed collaboration to develop a workshop incorporating the construction of an aesthetic garland using paper circles of incrementally expanding size. These iterative forms provide the material basis for the SoS workshop (Figure 3).

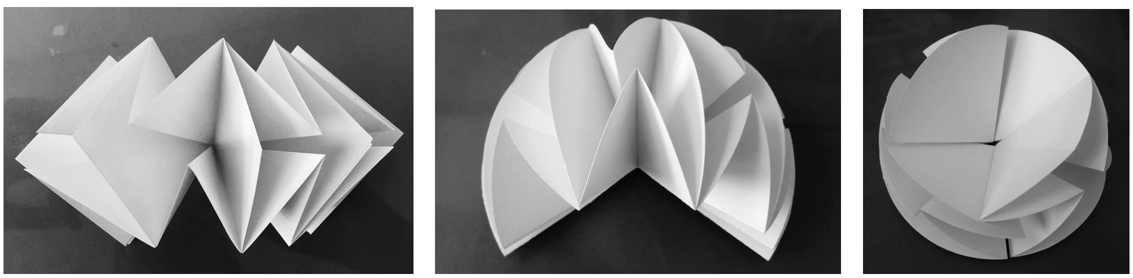


Figure 2: *Square and circular Whatman paper structures.*

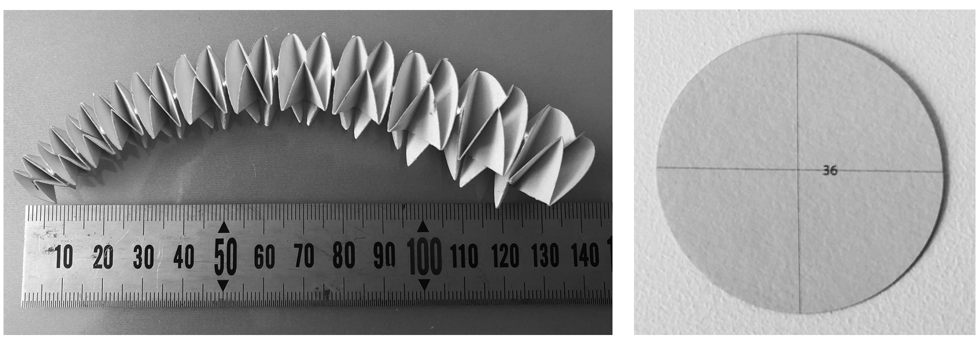


Figure 3: *Folded circles showing incremental sizes. Numbers and fold lines are indicated on the surface.*

Workshop Aim

The SoS experience involves visualizing a variety of math concepts through a session of mindful making. The model we use provides a visible learning experience of calculating common sectors, slices, segments, quadrants, and radians using paper and string, leading to discussion of formulas for calculating the area of a sector. Primarily, theoretical content includes the exploration of geometry, including the relationship with Pi, indicated in Figure 4. The aim is to encourage exploration of the math in order to understand its relevance to the creation of the aesthetic product. We consider the aesthetic product to be of equal importance to the aesthetic experience. Maps depict diverse geographical locations. The decorative element is our playful link back to Miura as seen in Figure 1. Our aim in this and previous workshops is to prioritize individual agency by offering time and space for engaging with making without too much facilitator intervention. All participants will leave the workshop with a beautiful self-constructed form made from iterated folded paper circles of increasing and/or decreasing sizes. They are encouraged to take ownership of their experience by approaching the task with mindfulness.

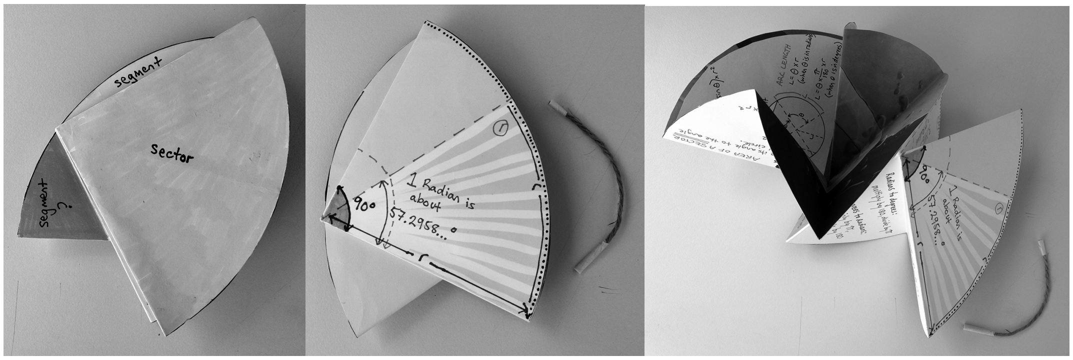


Figure 4: *Working with sector models to discover learning related to understanding geometry terms.*

Workshop Outline – the audience experience

Since the SoS workshop relies on assembling a set of individually folded circles, it is important to reiterate how the experience provides a variation of modular origami, based on collapsible origami, memory fold origami and versions of Miura-ori technique applied to one-way folding in alternate directions. It is not a single sheet with continuous tessellating folds. In the SoS workshop we glue the individual pieces together to form the garland-like chain. Beginning with an exploration of quadrants, sectors and segments, the workshop uses math to introduce the conceptual framework for the activity (Figure 4). Following experimenting and testing the construction techniques, participants are issued a set of paper circles of incremental sizes from around 30mm to 60mm diameter. These are the templates used in construction. Twelve step instructions are provided in Table 1, in alignment with illustrated guidelines in Figure 5.

Table 1: *Workshop Folding Instructions*

Step 1	Assemble the pre-scored circles in descending order from largest to smallest. Select the largest circle. Dotted lines indicate *Valley Folds* (down) and solid lines indicate *Mountain Folds* (up).
Step 2	Valley fold and unfold indicated by the 2 dotted lines that intersect at 90°.
Step 3	Turn the paper over.
Step 4	Valley fold and unfold indicated by the dotted line that intersects at 45°.
Step 5	Pop the center point up and squeeze left and right quadrants to meet in the centre.
Step 6	Press the paper flat to reveal a single quadrant of the circle.
Step 7	Rotate the sector 90° counter-clockwise (towards the left).
Step 8	Place the largest and next largest sector with the tips meeting as indicated.
Step 9	**The smaller sector always goes on top of the one before (larger sector).** Slide the smaller sector across so that the top tips meet. Hold the tips together and rotate the top sector so that right angle corner meets the edge of the arc beneath.
Step 10	Glue the sectors in the position as shown.
Step 11	Continue making your sectors using steps 1 - 6 as above. We recommend you glue each sector as it is folded, making sure that the top tips meet.

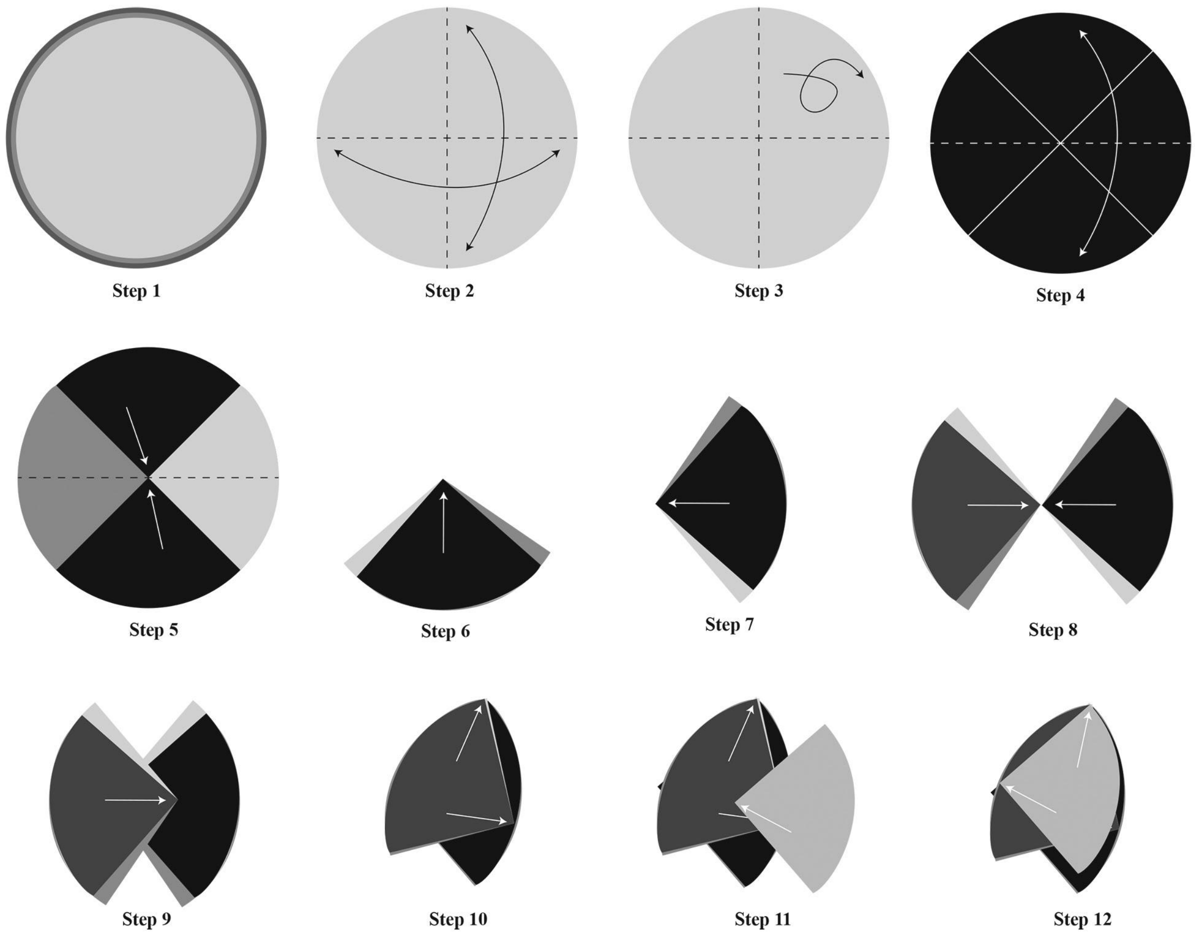
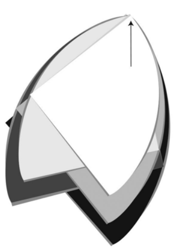


Figure 5: *Instructions for folding the sectors.*



Note that the third sector is positioned in the same direction as the first sector. This denotes the alternating stacking pattern (Figure 6). When the pattern is unfolded, the chain can be viewed as a series of creased circles of descending/ascending sizes, made with a combination of hill and valley folds (Figure 7).

Figure 6: *Stack of folded sectors.*

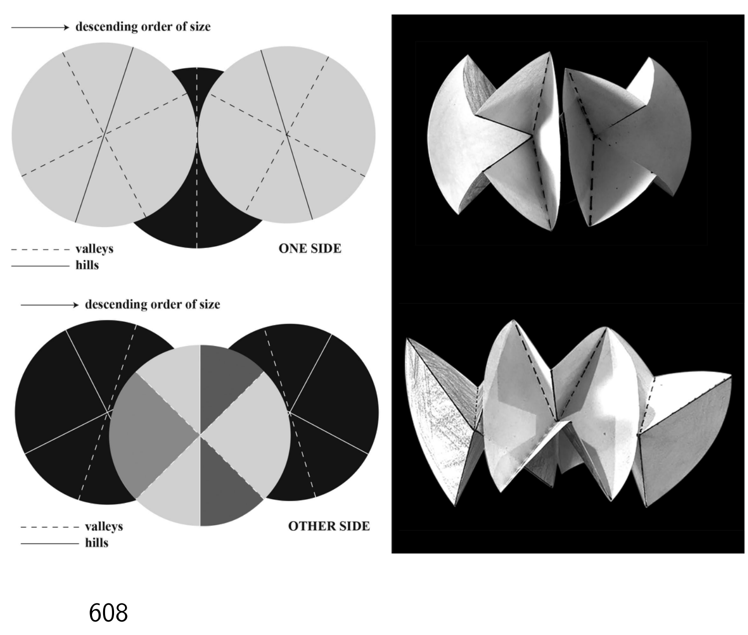


Figure 7: *The sector chain in descending order of size, showing the beginning of the sector chain from both sides*

When you have finished attaching all your sectors together, you will have a stack of sectors ranging from largest to smallest, all orienting with top tips meeting (Figure 6). Squeeze the structure tightly. Then let it go! This is your synthesis of sectors (Figure 8).

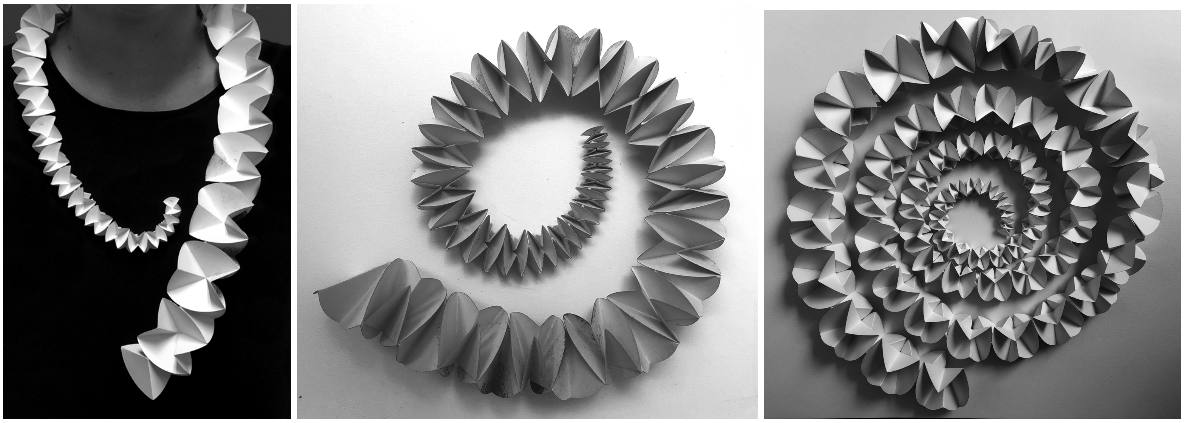


Figure 8: *Prototype artefacts developed for SoS workshop.*

Learning Opportunities

Learning in the SoS workshop can be viewed as a creative encounter in STEAM. That is, surprising creativity discovered by embedding the arts and design in STEM (science, technology, engineering and math). Surprising creativity prepares the mind for eager identification of creative agency, the potency of risk-taking and power of shifting ideas into action [5]. STEAM settings often absorb the interplay of personal characteristics of learners of all ages as well as the interactive environmental factors in which learning takes place. The SoS workshop opens up explorations into broad ranging ideas encompassing:

- Origami and its variants – Modular, Collapsible, Rigid, Technical (Sekkei) [7] [8] [12]
- Practical 2D to 3D explorations in art and design.
    - relationships between the circle and the fold, curves and angles, sharp and contour, iterative units of equal and different sizes. We call these 'flat to form' experiences. A good resource for experimentation is *How To Fold It* by Joseph O'Rourke [12]
- Folding and its applications in art, design and industry including exploration of Muira-ori and the negative Poisson ratio and the science of auxetics: [8] [17]
    - applied in sustainable fashion such as Petiti Pli [17]
    - and the intersection of metamaterials with programmable matter crystallography [9]
    - Traditional to exotic materials formation via microscopic structural alterations [11]
    - in space exploration [10]
- Mathematical theorems: Kawasaki Theorem [7]
    - Exploring challenges related to flat foldable valley-mountain patterns such as Robert Lang's general-purpose origami design/analysis package [8]
- Biomimicry in design and mathematics [2] [14]
    - Vertebral column and its articulation
    - Nautilus shell (Ammonites) as a symbol of proportional perfection: Golden Ratio, Phi, Fibonacci sequence
- Why Pi? See Figure 4

Conclusion

The art of origami has received considerable attention in recent years. Its application to new and emerging technologies starts with simple exploration in paper folding. In the SoS workshop, the folding activity is a variation of modular origami where multiple units are assembled to create a larger, more complex form. Each individual piece is a circular version of a "Turkish Map Fold" which can be categorised as "shape-memory origami". Its mechanical behaviour is reliant on the properties of material memory such that, after unfolding, the paper structure can be easily refolded and returned to its compact shape. This method of folding allows the paper to be opened and closed in one swift motion, like a map. Differentiating the size of the circular papers used in our workshop afforded us a surprising new discovery: a flexible ammonite-like form that you can wear! It is this discovery that we share with interested enthusiasts today. The SoS workshop provides participants with a unique transdisciplinary experience by making significant connections between mathematics, engineering, design and art making. Such hands-on experiences make math and science visible and relatable to all, while reinforcing the value of STEAM connections in lifelong learning.

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