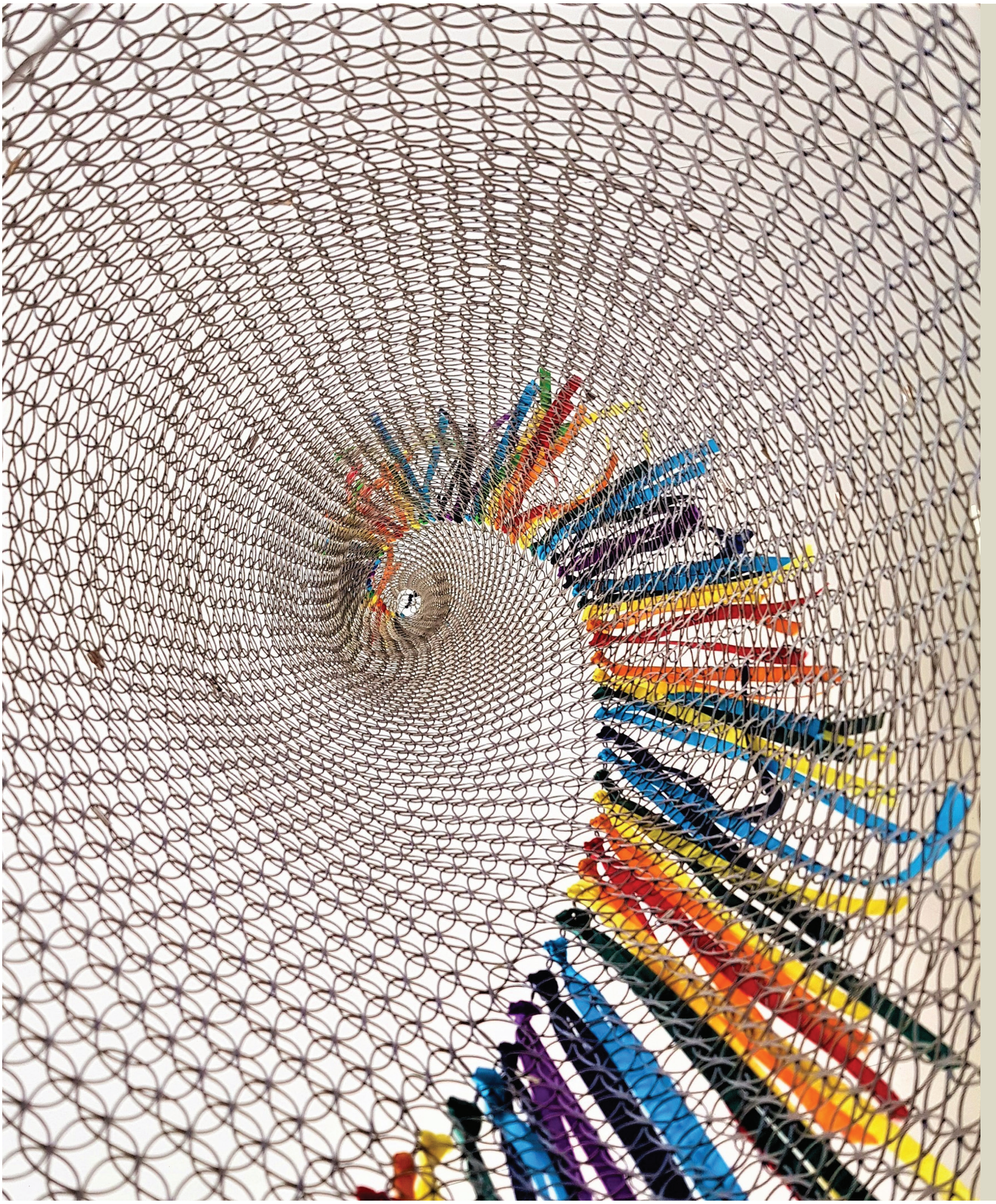

Basketry and Mathematics: Reflections on Curves and Surfaces

Stephanie Bunn and Ricardo Nemirovsky with the Forces in Translation Research Group, including Mary Crabb, Geraldine Jones, Hilary Burns, and Charlotte Megroureche

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Abstract | If fingers and fiber elements make textiles through gestural hand movements and spatial techniques, and lines, space, and movement create geometry, then can making textiles be a form of mathematical understanding? This article considers this question through the studio research of the Forces in Translation (FiT) project, which explores the links between basketry and spatial and geometric cognition. Taking an anthropological approach to learning, the group has conducted research through studio trials, allowing understandings and insights to emerge through examining how specific basketry practices and techniques converge with mathematical and spatial forms of inquiry. This approach neither puts basketry (as an arts subject) at the service of mathematics, nor uses mathematics (as an abstraction of everyday forms and structures) as inspiration for making baskets. Instead, the project approaches the two disciplines by conducting them together in a nonhierarchical way.

The article discusses, firstly, how basketry is a form of textile. Secondly, FiT's approach to textiles and mathematics is expanded upon, along with its context within these disciplines. Finally, the dynamic between craft and textiles as forms of geometric cognition is discussed in relation to case studies from the FiT project, illustrating how a hands-on approach—a material, tactile, mathematical approach—can be of great significance for the development of creative geometric and spatial cognition. As the product of ethnographic research through studio trials, this article inevitably takes a reflexive approach to participants' experience. In order to understand and share new and old expertise, there is also an auto-ethnographic element. Hence, participants' reflections on the process will be cited.

There will always be a place for the handwork… Not as a sentimental relic…or as an escape from the present…but as a genuine factor in a fully contemporary life.
Alistair Morton, 1944[1]

Basketry, the Textile

Readers may already agree that basketry is a form of textile. Ed Rossbach's *The New Basketry* of the 1970s did a great deal to show how basketry can be considered as a constructed textile or a form of textile art.[2] Even before this, weavers from the Bauhaus, artists such as Mariska Karasz, and tapestry weavers such as Lenore Tawney drew upon basketry's common practices with twining, tatting, and looping to create beautiful textile forms.[3] Irene Emery might have preferred the more etymologically precise term "fabric" to be used, since the derivation of the European term "textile" is from the Latin *texere* "to weave," and basketry includes a range of techniques from twining, folding, and looping to plaiting.[4] However, as Denise Arnold argues, to define world textile practices in terms of the Indo-European language group is both Eurocentric and restrictive.[5] The Textile Museum

1 Parsons and Hughes 2022.
2 Rossbach 1973; Rossbach 1976.
3 Constantine and Larsen 1972.
4 Emery 1966.
5 Arnold 2015.

FIG. 1
Cycloid looped baskets from Kalimantan. Collection of J. Gathorne-Hardy. Photography by Stephanie Bunn.

itself houses diverse nonwoven textiles, from felt and bark cloth to lace and patchwork, and following this more open approach, this article considers basketry among these textile forms (fig. 1).

Across the world, regional basketry forms such as cycloid looped and twilled containers from Kalimantan in Borneo, twined baskets from the American Northwest Coast, or Indian *kottan* work—all of which may use diverse techniques in one basket—reveal significant overlap with other textile skills.[6] Basketry's deep history also reflects this convergence with many textile practices. As a form of interlacing or intertwining created without a loom, basketry may well have preceded practices such as loom weaving, *nålbinding* (knotless knitting), or tatting. Plant-fiber mat making would likely have encompassed both. Indeed, it is most likely that these interlacing practices developed through curiosity, experimentation, and play with diverse textile fibers and techniques, but put to different uses in different contexts in the past. Multiple historical examples, from the Danish Egtved girl's string skirt (1370 BCE),[7] to the recent discoveries of the 10,500-year-old basket in the Qumran cave,[8] to textile fragments from sites such as Çatal Hüyük,[9] all suggest a crossing over of basketry with other textile skills.

Characteristic features of baskets include the use of techniques that employ tension or friction to hold the basket's structure together. Such techniques are often common to other textile forms. Basketry materials are almost always plant based. In contrast with many other textiles, however, baskets are often semirigid in structure rather than soft and they are also three dimensional. One further characteristic of basketry, as claimed by Otis Mason more than a century ago, is that baskets cannot be made by machine.[10] Indeed, even in the digital age, this is still the case. This is partly due to basketry's three-dimensional form and because basket making is an emergent process, whereby the structure of the basket creates its own weaving frame as it develops. This, together with the use of plant fibers, which are often short, irregular, and varied, makes it particularly difficult to develop an algorithm with which to develop a machine-made basket. It may be possible to reproduce a basket on a 3D printer, but this will not hold together using the same forces as created by the interlacing used in a basket.

6 Bléhaut 1994; Farrand 1900.
7 Barber 1994.
8 Holmes 2021.
9 Mellaart 1966.
10 Mason 1895.

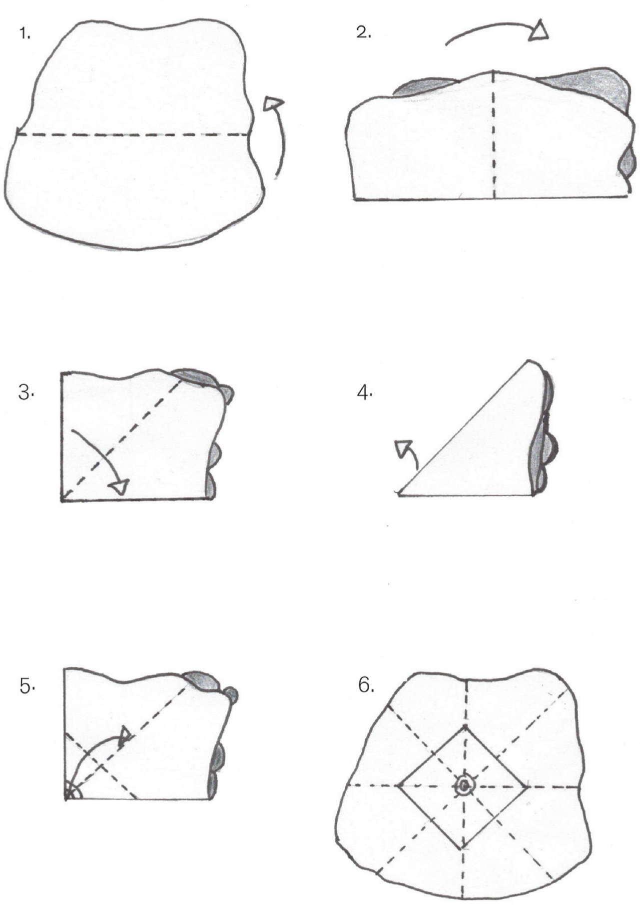

FIG. 2
Folding an irregular piece of paper or fabric into a square, after Fröbel. Drawings by Stephanie Bunn.

Research through Experience

The Forces in Translation (FiT) research project set out to explore how the manual dexterity used in textile-making practices such as basketry provide an embodied resonance with mathematical practices, especially geometric learning and spatial understanding. The project team wanted to discover how using hand skills may enable mathematical intuitions to emerge, leading to understanding, which is something often considered to take place exclusively in the mind. Given the continued phasing out of hand skills in contemporary education, along with the increasing amount of digitization in education, this approach is very timely. It is important to maintain diverse and flexible pathways to developing human cognition. This has become even more relevant, since more learning moved online as a result of the COVID-19 pandemic.

Initial public responses to the FiT project suggested that a connection between mathematics and basketry either seemed improbable or, alternatively, very appropriate. While the group considers there to be multiple convergences of practice, nevertheless, many learners may consider math to be somehow a more perfect, imperceptible, and sometimes inaccessible expression of the world. People experience their daily lives as if there is an everyday world and a mathematical one behind it, with most bodily skills, from basketry to dance to building, viewed separate from mathematics.

The FiT approach parallels the work of the nineteenth-century German educationalist, Friedrich Fröbel,[11] American philosopher John Dewey,[12] ethnomathematician Jerry Lipka,[13] and that of British educationalist Mary Harris who developed the Common Threads project in the late twentieth century.[14]

Fröbel's aim was to give young learners a range of "gifts," which enabled them to discover mathematical patterns and rules through playing with materials and three-dimensional forms. These gifts included paper weaving and paper folding. For example, he showed how a rough-edged, irregular piece of paper could be folded quite simply and exactly to create a perfect square (fig. 2). From this, he showed how by folding the square lengthways, a rectangle could be formed that was half of the square. He then showed how the same square could also be folded diagonally to create a triangle. Since the square could be folded in half, both horizontally and diagonally, he was effectively illustrating that both shapes—the rectangle and the triangle that he had created—were half of the square. and had the same area (fig. 2). One of his conclusions was that this practical activity shows that a "half is the same as a half." In other words, he

11 Friedman 2018.
12 Dewey 1934; Dewey 1997.
13 Lipka et al. 2015.
14 Harris 1997.

illustrated that abstract mathematical notions such as "a half" could be applied in different contexts.[15] Furthermore, through folding, a person can develop a practical, valid intuition of equivalences. This also illustrates how mathematical forms can be transformed through dexterous manipulation and new mathematical ideas developed. The haptic folding activities enable a mathematical truth to be experienced visually, and the notion of a half to be abstracted without any need for counting.[16]

Lipka's work with Yup'ik elders at the University of Alaska Fairbanks shows some parallels with Fröbel's approach. In this case, symmetries were developed and equivalences measured by centering the crossed index fingers as "the beginning of everything."[17] The crossed fingers signify an "embodied abstraction," which is the starting point for many practical activities. This could again be illustrated through folding irregular materials to make clothing or patterns, thus establishing a line of symmetry. For example, similar techniques could be used for everything from star navigation to making snow shoes. In this Yup'ik "culturally preferred way of perceiving," everything has a center. This illustrates how scale, proportion, and balance are practiced in many everyday activities, not just among Indigenous peoples, but by many practitioners of hand skills worldwide.[18]

Mary Harris's Common Threads project focused on how making cloth and weaving baskets has been women's work for millennia, and yet the mathematical expertise in these practices has been rarely acknowledged or given the status that has been given to formal mathematics.[19] Woven, braided, and knotted textiles entail systematic thought, tallying, counting, and an understanding of geometric patterning and spatial relationships. The *Common Threads* exhibition toured internationally for six years, providing educational experience through the mathematical context of practicing textile techniques and access to multiple examples from embroidery to twill basketwork.

All these thinkers have argued for the value of haptic experience in learning mathematics. In this sense, they are in accord with the American pragmatist John Dewey, who argues that education requires interaction with others and with the environment beyond the body. "Experience does not simply go on inside a person," says Dewey.[20] For a "real experience," such as that which constitutes learning a skill, there is unity; each experience is marked by a quality, an emotion, a sense of purpose and care, a doing or a making, and a rhythm, much more than a simple train of ideas or logical sequence. This is because experience is "integral."[21] In other words, experience is a whole, a consummation, and it cannot be broken into constituents at the time of action. This can apply equally to learning a practical skill or developing a mathematical intuition.

Alongside experience and practice, for the FiT group, the anthropological investigative process is an important aspect of how people learn. That investigative process is qualitative and open, a kind of anthropological intuition that follows a Malinowskian "foreshadowed problem."[22] In this regard, anthropology, like art, provides a particular approach to learning, which is emergent and follows experience. Anthropologists are not hard scientists; they do not conduct repeated, quantifiable, testable studies that are more associated with mathematical research. They do not try to prove things, although they are interested in patterns of life. Through participant observation, anthropologists take part in what goes on, learn through doing, and try to observe everyone in action together.

This brings a qualitative, practical, and material approach to mathematical practices. The anthropological approach is important, because while

15 Cited by Friedman 2018, p. 6.
16 Friedman 2018, p. 7.
17 Lipka et al. 2015, p. 5.
18 Ibid.
19 Harris 1997.
20 Dewey 1997, p. 39.
21 Dewey 1997, pp. 205–7.
22 Malinowski 1987.

mathematics may appear to be about abstract rules and patterns, it is also social and cultural—dealing with skill and memory, aesthetics, and feelings of enthusiasm and ignorance—and thus has a qualitative experience, even when dealing with abstraction and numbers.

Anthropology, Ethnomathematics, and Textiles

There is a history of anthropologists and ethnomathematicians working with textiles. Ethnomathematicians working in the Andes, such as Marcia Ascher, Carol Mackey and Gary Urton, have studied *khipus*—knotted, spun cords used by the Inca for counting and reckoning before and after the Spanish conquest of South America in 1532; khipus are still in use in the Andes today.[23] In Africa, Paulus Gerdes worked with basket makers in Mozambique, exploring the geometric knowledge in regional basketry practices,[24] while Helen Verran worked with Yoruba children in a Nigerian primary school, revealing how Yoruba mathematics is not absolute, but relational.[25] In the Pacific, Deacon and Westwood studied the mathematical potential of sand drawings in Vanuatu in 1934,[26] while more recently Dinah Eastop, Robyn McKenzie, and Eric Vandendriessche all revealed different perspectives on Australian and New Guinean string figures.[27]

All these studies indicate that people do multiple forms of mathematics during their daily activities, which until recently have included all manner of textile work. They count, calculate, measure, problem solve, and work out proportion, often in conjunction with singing, storytelling, communicating about family and kinship, and manipulating diverse forms of natural materials. Many ethnomathematical studies involve textiles, which themselves are made without using formal mathematical methods such as geometry, algebra, or probability theories. In this regard, their work all reflects Trevor Marchand's argument that "bodily practices generate distinct kinds of mathematical sensibilities that enable people to fluidly work things out and to problem solve in the flow of work, play, and everyday activity."[28]

Several critiques have been levelled at ethnomathematics. A common one is that the focus in ethnomathematics is almost always on numbers and counting, which is often set up as concrete in contrast to Western abstraction. That is, people who practice these skills are viewed as not doing abstract calculations as numbers are always in relation to objects, a view which has been most prominently refuted by Jadrun Mimica and subsequently also by Helen Verran.[29]

A second, linked critique by Marchand is that ethnomathematics almost always references back to a Western notion of formal mathematics as the ultimate abstract and universal form in which all mathematics is considered to be grounded.[30] In other words, the suggestion is that there is only one "real" mathematics. It is common to consider this as the mathematics that underlies measurable and spatial experiences in people's daily work. This is sometimes linked to the way that many ethnomathematicians, such as Lipka, Gerdes, and Verran, have used diverse cultural mathematical practices for education in the regions where they work.

These are somewhat imprecise critiques, in that ethnomathematicians, such as those mentioned above, often make it very clear that there are other forms of, or perspectives on, mathematics distinct from Western forms, and that there is great value in learning from them. Indeed, they frequently critique the assumption that Western mathematics is the "one true math." Lipka, for example, describes how Yup'ik measuring takes place in a "nonnumeric environment,"

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23 Ascher and Ascher 1981; Ascher and Ascher 1986; Urton 1997. For contemporary use, see Mackey 2002.
24 Gerdes 1999; Gerdes 2010.
25 Verran 2001.
26 Deacon and Westwood 1934.
27 Eastop 2007; McKenzie 2011; Vandendriessche 2014.
28 Marchand 2018, p. 303.
29 Mimica 1988; Verran 2001.
30 Marchand 2018.

relating more to comparison of quantities and ratios.[31] Perhaps because of this diversity, however, ethnomathematicians may use their background in Western mathematics to unpick what in the others' practices counts as mathematical. In this way, they may rely on the canons of Western mathematics to "see" mathematics happening elsewhere. But, as Helen Verran says, such an approach tends to explain away difference rather than reveal new perspectives and possible significant insights raised by another form of mathematics.[32] It is important to attend to the possibility that, as Marchand says, there may be "entirely different forms of mathematics that may not in any way resemble academic mathematics."[33]

More theoretical anthropologists have drawn on mathematical systems to provide insights to social practices such as kinship, myth, and cosmology. These include Claude Lévi-Strauss, Jadran Mimica, and Susanne Kuchler. Lévi-Strauss's structural anthropology could be characterized as mathematical, in that he argued that the human mind exhibits certain universal characteristics, drawing comparisons between how the human mind works and the way a computer processing system might work.[34] But he was really applying theories from structural linguistics and linguistic coding, rather than mathematical theories, to anthropological concerns such as kinship systems, myth, and art.

Jadran Mimica took a more phenomenological, embodied approach to Iqwaye counting systems in Papua New Guinea.[35] Exploring how the Iqwaye use the body, such as fingers and toes, to count, he argued that this is not because they lack the capacity for abstraction. Rather, he suggests that their number system reflects the parallels they perceive between human identity and the body, and the world and the cosmos at large.[36]

Susanne Küchler's work has, perhaps, the clearest links with textiles. Küchler applies topological geometry to knotting on the island of New Ireland in Papua New Guinea, and to binding across the Pacific region in general, in relation to kinship and ritual.[37] She uses this to analyze a New Ireland *malanggan* ceremony, in which *malanggan* carvings, hollowed out wooden knot-like forms, are destroyed following memorial rituals, acting to release the souls of the deceased. Küchler draws upon knot theory, an important branch of topology, because knots "both embody mathematical principles and have at the same time a tendency to evoke a range of emotional and personal sorts of thoughts." Knots can "externalize non-spatial problems in a distinctly spatial manner," all the more so because topologically the space between the knotted surfaces is of equal interest to the knot itself.[38] For Küchler, however, topology is more a theoretical model than a concern with mathematical practice.

Interdisciplinarity in Mathematics and Textile Research

For the FiT group, interdisciplinary research is not a study of basketry and mathematical practitioners, nor does it consider that the different disciplines are part of a hierarchy where one is in the service of the other. FiT group members explore these concerns together. However, interdisciplinary study of mathematics and basketry means that each participant has a different specialized knowledge, but also areas of ignorance. In investigating questions together, rather than one discipline working at the service of the other, the FiT group adapted Paul Klee's approach where making and thinking have to go together, which he utilized while making art when writing his lectures at the Bauhaus. Thus, the FiT group

31 Lipka et al. 2015, p. 2.
32 Verran 2001.
33 Marchand 2018.
34 See for example Lévi-Strauss 1966 and Lévi-Strauss 1963.
35 Mimica 1988.
36 Mimica 1988, p. 102.
37 Küchler 2001.
38 Küchler 2001, p. 5.

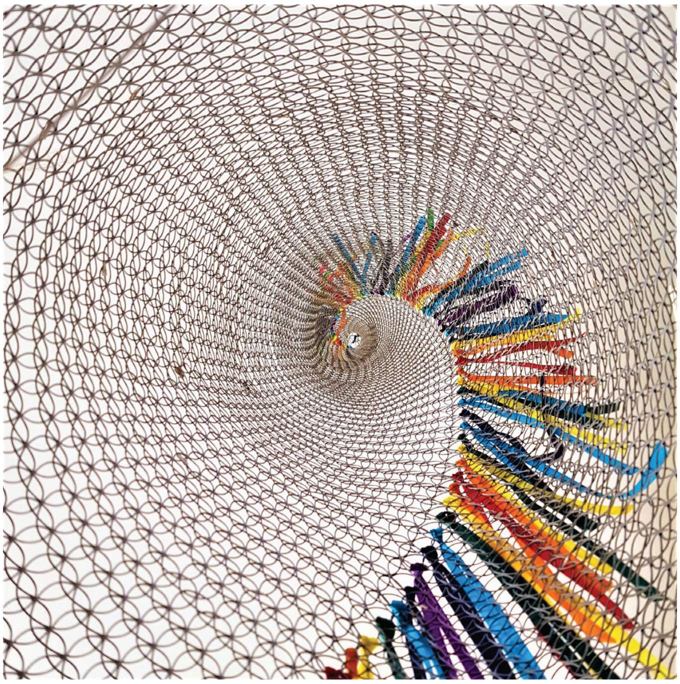


FIG. 3
Geraldine Jones, *Looped Structure.* 2021, stainless steel wire rope, 153 × 153 cm (60 × 60 in). Photography by Geraldine Jones.

chose specific problems and explored these through multiple approaches of practice, discussion, reading, talks, and filming.

Sometimes group members with little mathematical background felt lost in the geometric complexities of what the group did; sometimes mathematicians found it difficult to grasp the dexterity of more complex basketry techniques. One group member, basket maker Geraldine Jones, claims never to have been good at math as a student. Yet her work is inspired by growth patterns in the Fibonacci series and hyperbolic forms, revealing that one may have mathematical aptitude without translating this into formal mathematics. Geraldine Jones's work has shown that basketry techniques such as cycloid looping can stand alongside crochet in hyperbolic geometry (fig. 3).

A second group member, Mary Crabb, is both a textile artist and a STEM ambassador for mathematics, tutoring in math when she is not leading basketry courses. She is able to bridge both disciplines with ease. The precision of her notebooks would be the envy of many mathematicians. Other members bring different experiences, such as material processing, contextual cultural knowledge, or educational expertise, which may appear less directly linked, yet are essential for the way group members' learning styles and skills complement each other to build a rich practice.

Learning the necessary math sometimes requires more information than can be digested over the short period of a studio, and subjects have to be revisited as homework. For example, the resident mathematical educationalist Professor Nemirovsky set exercises on mirror symmetry or curvature during sessions on looping or lines, the reasons for which came into focus several months down the line. This perhaps reflects Dewey's notion of experience, which has to be complete and resolved for it to become embedded. At other times, the group members focused on a technique or material, only to later learn that techniques overlap and materials work differently in each form.

Group members of each discipline also asked different questions of the same experience. Makers tended to ask how a piece was made and what it was made from. Mathematicians tended to reflect on what theorem, proof, or form a particular structure illustrated.

The case studies below illustrate key themes that have arisen again and again during the project. Critically, the materiality of basketry construction has meant that everything is in three dimensions, even when it appears to be flat surfaces or lines. This is in contrast to classical Euclidean geometry, where diagrams and drawings usually address problems through depicting them on a flat plane. Geometric marks and lines are usually abstract and not perceived to take up space, acting as "ghost-lines" as Tim Ingold describes.[39] In contrast, basketry lines, as Buckminster Fuller described in relation to his built structures, are energy actions that exist in the universe. Basket makers' lines take up space and are held together by forces. They may be twisted ropes held together through tension, plaited bands held together by friction, or handles, edges, and borders. Basketry surfaces will also be double layered due to

39 Ingold 2007.

the use of weaving, twining, or plaiting techniques, which provide a quite different kind of structure than, for example, a model generated on a computer screen. So, three dimensionality is a core theme of the group's investigations.

Running through every FiT studio has also been the notion of different kinds of space and surfaces. Classical Euclidean geometry, developed 2000 years ago, tends to work best in flat space, but there is also spherical space and hyperbolic space, all of which can be expressed through basketry. While Euclidean geometry provides a way to measure our physical, three-dimensional environment in abstract terms, aspects of it do not work so well on curved surfaces such as spheres or undulating forms. A sphere has constant positive curvature, in that at any point curves will extend away at a similar angle, creating a kind of dome. An undulating, hyperbolic form, such as the meeting point between the crown and the brim of a woven straw hat, has negative curvature because at that point, sideways curves from left to right will be convex, while the curve down from crown to brim will be concave. Different kinds of geometry are needed to work with these kinds of space. Gradually, through the different studios, questions about these different forms of space have been emerging and explored.

Case Study 1: Turning a Plait and Skew Cubes

Turning a corner from base to sides in a basket means definitively going into three dimensions, so corners and curves are very important. The group chose to try this in plaiting, a technique of interlacing fibers where both elements are active. Although plaiting may on occasion look like weaving, it is closer to hair braiding than to weaving on a loom or to standard British stake-and-strand basketry. Stake-and-strand basketry usually employs a strong, but fixed, warp; stakes, which are vertical and usually considered passive; and interlaced wefts or strands, which weave horizontally between the stakes. The structure holds together through tension. Willow, a filament, is the standard material. Plaited basketry, in contrast, uses flat materials such as pandanus, rush, or palm, rather than filaments like willow, bamboo, or rattan. All the elements are moved during the interlacing, and the object is held together by friction across the flat surfaces of the material rather than by tension.

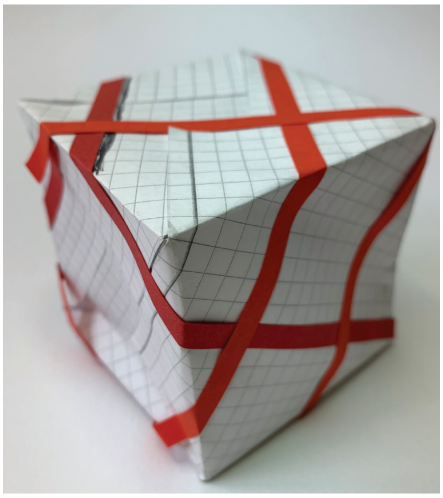
Because all strands are active in plaiting, this means that plaited basketry can be worked on the diagonal rather than just horizontally and vertically through its creation, such as with stake-and-strand baskets. This makes for an interesting change of perspective. Küchler has suggested that living in an environment where specific textile-making techniques predominate, such as knotting or twining and plaiting or weaving, could parallel or reflect different forms of social practices, such as kin relations or ritual practices.[40] Lipka's example of centering, mentioned above, also suggests this. The FiT group members were interested to explore whether this possible change in perspective reflected different ways of mathematically thinking through technique and the bodily gestures involved.

Plaiting is one area of basketry that mathematicians have explored in great depth, particularly computer modelers. However, they tend to treat the materials on screen as if they have no substance or qualities. Computer modeler Phil Ayres, for example, specifies to "Imagine this material is flat uniform steel"—in other words, neutral and smooth.[41] The concern with computer modeling is thus that on-screen diagrams may look three dimensional, but they have no substance or material qualities.

In preparation for plaiting round corners, the group had read papers by Tibor Tarnai and Felicity Wood on skew cubes.[42] These are cubic forms made from graph paper, where the sides are folded obliquely across the vertical and horizontal axes of the squared paper to create diagonally skewed

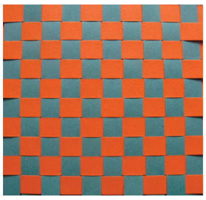
40 Küchler 2001.
41 Ayres et al. 2018.
42 Tarnai n.d.; Wood 2007.

FIGS. 4A AND 4B
(A) Graph paper cube,
(B) skew cube created by Mary Crabb. Photography by Mary Crabb.


A


B

FIG. 5
10 × 10 base for woven paper cube created by Stephanie Bunn. Photography by Stephanie Bunn.

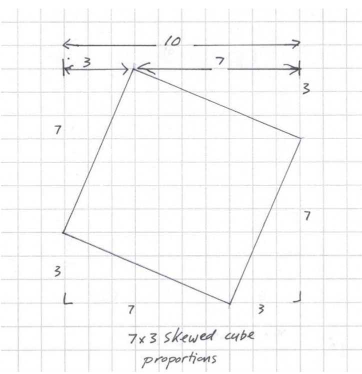


boxes. The mathematical challenge was to imagine how many times one has to follow a graph-paper line around to reach the original starting point (figs. 4A and 4B).

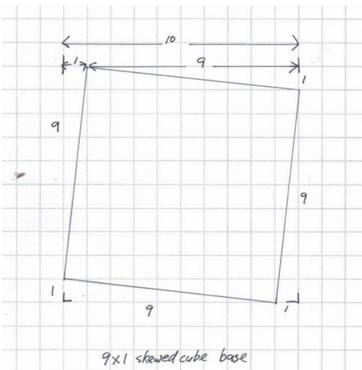
The skew was created by taking a ten-squared graph-paper cube, making it from strips, and skewing it diagonally from the vertical (figs. 4A and 4B, 5), to create, for example, a 7-square by 3-square triangle along the base to form the new edges of the cube. Having constructed these in graph paper, the group aimed to remake them using plaited paper strips. So, the plaiter had to configure the diagonals of the plaited cube in parallel to the graph-paper cube by skewing them at different points along the sides of the plaited square base. A true diagonally plaited cube would have the diagonals at 45 degrees at the corners, and the square base would consist of two right-angle 5-square by 5-square triangles. It would count as a 5:5 skew. The group's aim was to plait cubes in ratios of 1:9, 2:8, 3:7, 4:6, and 5:5—the latter being a true diagonally plaited base (figs. 6A–6C). As Geraldine Jones explained:

> *Making a graph paper cube using a ratio of 1:9 to fold the sides proved impossible for me, scrunched it up as a bad job and wove the next one using phormium (plant) strips and a 4:6 ratio…I'm not quite sure what this exercise is achieving but will have another go at the paper version and the objective may become more apparent.*[43]

FIGS. 6A–6C
A) 7 × 3 proportions for a 7 × 3 skewed cube. B) 9 × 1 proportions for a 9 × 1 skewed cube. C) 5 × 5 proportions for a 5 × 5 skewed cube. All illustrate how this is on the diagonal. Drawings by Stephanie Bunn.



A



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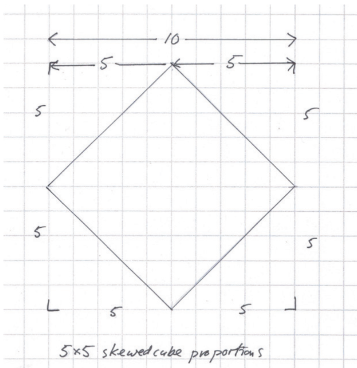


C

43 Jones n.d., March.

FIG. 7
Top view of graph paper and plaited skew cubes created by Mary Crabb. Photography by Mary Crabb.

Mary Crabb, working with red and black paper strips, added that:

I usually work small-scale and quickly found [the big paper] quite cumbersome to work with, but decided I should complete it and make some smaller samples afterwards. The big question I was wanting to answer, was…what happens to the pattern on the top face, when the cube is enclosed?…Would the [red and black] checkerboard base be reflected on the opposite face? The pattern that had started to form on the sides, had a reassuring sequence to it. Alternating rectangles 7 × 3 squares in both plain and checkerboard. But…I discovered that some of the strands resolved, whilst others conflicted. Why?[44]

Remarkably, on the top surface of the plaited cube, there was more than one possible outcome because the interlaced strands coming to meet each other were often in opposing colors (fig. 7).

While computer modelers had trialed skew cubes on screen or made them as printed cutouts, no one, it seemed, had actually plaited them and realized this possibility. Mary Crabb tried drawing her cubes on graph paper and explained:

I very quickly came to realise that colouring individual squares on a diagram detaches from the process of weaving. The woven strands are dynamic, with movement and direction. The coloured squares are static and no longer relate to the strand, their sense of being part of something greater is lost. They are just squares.[45]

One learns differently by practically weaving a form than by imagining it. A plaited skew cube is double layered because it is interlaced, but imagined models rarely take this into account. Mary Crabb has since developed her investigation by weaving multiple forms of skew cubes in different colors and ratios, drawing, stitching, and, most recently, in knitting. A fuller publication of her research is still to come.

Case Study 2: Looking into Looping: The Trefoil Knot

The group's studio trials, *Looking into Looping*, took place during COVID lockdown and were therefore online. This was a challenge but enabled people to explore both the benefits and limitations of online learning through experience. The two key themes explored were: 1) topology through cycloid weave and simple knotting, and 2) curvature through windmill loops. The former is the topic of case study number 2.

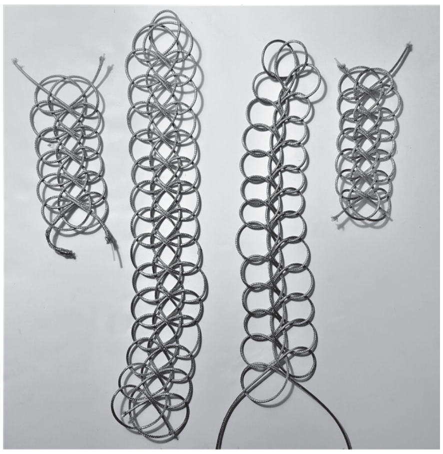


FIG. 8
Details of cycloid weave created by Geraldine Jones. Photography by Geraldine Jones.

44 Forces in Translation 2020a.
45 Ibid.

Initial interest grew out of Geraldine Jones's passion for cycloid weave, which she works in steel wire rope (fig. 8). Cycloid weave, as explained by Geraldine Jones, does not fit quite into any of the main accepted basketry techniques of plaiting, coiling, and twining. It is almost, but not, a knot. It has an affinity with crochet and is a technique with strong geometrical patterning, which can be eased and squeezed into many forms.[46] The technique is still practiced in Borneo where it is applied to long lengths of rattan to make back baskets.[47]

Cycloid weave also has great potential for understanding the mathematics of growth and hyperbolic surfaces if made using exponential increments, and it is well suited to Geraldine Jones's interest in the Fibonacci Series. In this, as mentioned, it is also one of basketry's answers to creating hyperbolic planes.[48] Cycloid weave also helps make translations between topological knots and cycloid loops, so it was a good way for those of the group who were struggling with topology to learn.

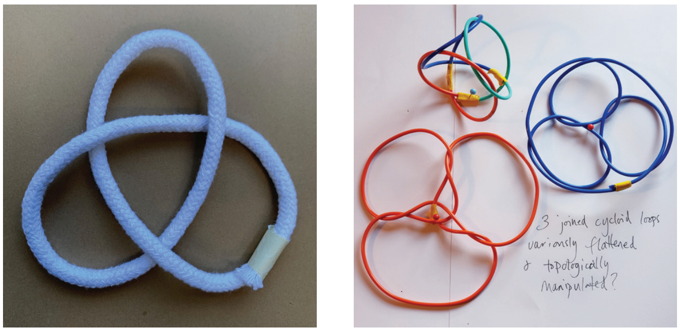
The group's introduction to topology began with an introduction to knot theory by working with the trefoil knot (fig. 9A). In topological terms, a trefoil is a knot with three crossings, that is, places where two strands cross each other, and is the simplest kind of nontrivial knot there is. The group members explored this knot in both classic topological form and through the cycloid weave (fig. 9B). In topology, knots have to be imagined as if projected in two dimensions where the trefoil clearly does have three crossings. In this case, it is "made" from a continuous strand of material with no tangible substance. Making a trefoil out of real-life material in three dimensions, however, is different. To begin with, material can have a twist. Twined or spun rope, for example, would not necessarily lie flat when twisted into a trefoil. As Ingold says, a whirl, such as in a spun thread, is a movement. The very act of winding or spinning changes the material—here the cord or string with incipient movement—and there is "no line that has not first been spun" or else braided.[49] A braided cord would have less tendency to twist. So, lines themselves are generated with different qualities. What implications does this have for the more abstract topological form of the trefoil?

This led to a second, more profound, kind of observation. If one tried to make a trefoil out of a twisted cord in three dimensions, it was not difficult to achieve this with only two crossings. In the online studio, Stephanie Bunn held up her trefoil variation. Where there should have been three crossings, there were only two, because the twist in the trefoil string and its existence in three dimensions led to contact in just two places (fig. 10). Bunn expressed this by saying:

There is a way with the trefoil where you can get two crossings…it depends if you see it as…as two dimensional or three dimensional…for there to be three crossings, there needs to be [three points] where it touches…

The others tried this. Mary Crabb, also making her trefoil variation with two crossings (fig. 11), mentioned:

If I hold mine like that, I just get two crossings…My fingers are where the crossings are…If a crossing is a point of contact between two strands, then there's one here and there's one here.[50]



A B

FIGS. 9A AND 9B
Trefoil knot created by Mary Crab (A). Cycloid weave version of a trefoil knot with multiple crossings created by Geraldine Jones (B). Photography by Mary Crabb and Geraldine Jones.

46 Forces in Translation 2020b.
47 Bléhaut 1994.
48 See Taimiņa 2018; see also Knoll this volume.
49 Ingold 2015.
50 Bunn ms., November.

FIG. 10
Trefoil variation with two crossings in three dimensions created by Stephanie Bunn. Photo courtesy of FiT recordings, November 2020.

FIG. 11
Trefoil variation with two crossings in three dimensions created by Mary Crabb. Photo courtesy of FiT recordings, November 2020.

Thus, by bringing in real-life dimensions, touch, and physical manipulation, the possibilities of creating a trefoil with varying numbers of crossings becomes evident. What implications could this have for topological theory?

In summary, the practice of working in three dimensions, as opposed to visualizing the material projected in two dimensions, can produce different outcomes. If the trefoil is visualized as a projection, there will always be three crossings. But unanticipated things can happen in the shadow of a projection. As a physical knot in a real-life environment, it is quite possible to make a trefoil variation from a knot with two crossings. In physically making the trefoil, the combined qualities of touch and movement have been added to a situation that relied upon vision. This consideration could have the potential to enrich our understanding of space and produce additional lines of inquiry.

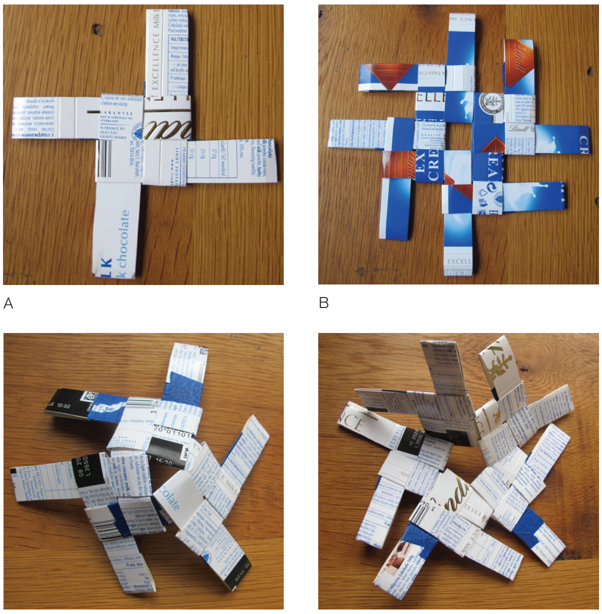
The second point concerns practice. Working in a group with different learning styles (visual, verbal, tactile, kinesthetic, and so on) and with different expertise, there will always be a range of learners who may be of equal ability but contribute diverse perspectives. A kinesthetic or tactile learner may sense the potential for exceptions to an approach that relies on the visual for proof or insight, while a visual learner may imagine the greater potential for a problem through thinking in terms of diagrams or projections, for example. These factors and perspectives need to be taken into account when exploring complex ideas and practices.

Case Study 3: Positive and Negative Curvature

The final FiT case study for this paper is an exploration of positive and negative curvature through windmill looping. This was held through an online knowledge exchange event in which fifty people participated. The aim was to provide an accessible investigation that participants could relate to in a bodily kind of way. Mary Crabb had found a set of homemade instructions for a "cigarette packet dog," which had formed a popular folk-art practice in the first half of the twentieth century in the United Kingdom.[51] These dogs were made from a technique called "windmill looping." They were reputedly made by sailors, prisoners of war, or tuberculosis sufferers from old Wills Woodbine cigarette packets in the 1950s. Mary Crabb had bought her homemade pack with instructions, which had been put together by Colin Fleming. The group made them from drink cartons called Tetra Paks instead of cigarette packets.

As discussed above, in regard to the body, positive curvature could be, for example, the top of a person's head. This is a curve that goes the same way in two directions to make a curved, dome form. A negative curve would be one that curves partly upward and partly downwards, such as under the chin or around the brim of a hat. To translate this for the Tetra Pak dog using the windmill loop, a positive curve could be the curve around the head, the end of the tail, or the base of the legs. A negative curve would be around the rise of the tail or where the legs join the body. Creating these curves reveals interesting linkages between curvature and different geometric planes (fig. 12).

51 Fleming 1998.



A B C D

FIG. 12 (above left) Tedi the Tetra Pak Dog created by Mary Crabb. Photography by Mary Crabb.

FIGS. 13A–13D (above right) Windmill loops showing A) single element, B) 4 connections, C) 3 connections, and D) 5 connections. Photography by Stephanie Bunn.

The usual woven element in windmill loops consists of four linked loops with a central gap with four edges where they meet. This would be extended in a plane by adding four additional loop elements to create a typical plane surface. If, however, one wants to create a positive curve for the end of the legs, one would connect just three loops in such a way as to make a triangle between them. If one wanted to create a negative curve for the top of the legs, one would make a pentagon introducing an extra loop, making five (figs. 13A–13D).

One way of thinking about how this works is to imagine a surface made from flat paper. Draw a square in the center of the paper, then draw two lines from neighboring corners of this square to the edge of the paper. Cut along these lines, remove the section between them, then join the edges that are left to form a triangle in the center and effectively a cone with positive curvature created by removing some of the surface of the plane. Alternatively, one could add an extra section of paper to the square and create a pentagon in the center. This would create negative curvature by increasing the volume of material in the plane. The windmill loops are alternative ways of creating these surfaces by decreasing or increasing material.

The discussion this provoked between mathematicians and basket makers was exhilarating. There is a pleasure in extending mutual understanding. Basket makers were, in general, intuitively testing and comparing ways and techniques to create curves and add or subtract to the surface of the dog's body, while the mathematicians were debating which theorem this activity illustrated. Was it Gauss-Bonnet, or was it Descartes?[52] This in turn linked to questions around hyperbolic curves, and just how much one could insert before things became hyperbolic. Yet despite the range of discussion, all had participated in the same activity. This way of thinking about curves also appealed to textile pattern cutters. Indeed, the aforementioned mathematical textile educationalist Mary Harris noted that mathematicians frequently enjoy the topology of pattern cutting.[53]

The discussion revealed how finding meeting points between embodied skills and mathematical formula can be illuminating from multiple perspectives.

52 See Taimiņa (2018) for a summary of the history of these mathematical thinkers.
53 Harris 1997.

A possible concern was the implicit assumption that the mathematical aspect, or the theorems were "the answer," or the final, real solution to the activity. This raised the question about the ways these two communities—basket makers and mathematicians—problem solve. For basket-makers, when confronted with a new basket or technique, the kinds of questions they asked frequently included "How is it made," or "What would happen if I tried it this way?" For a mathematician, the questions might be "Does it always do that?" or "How can I prove it?" It is interesting to speculate that, in all cases in this study, participants were looking for patterns and rules, whether in terms of technique or formula. The mathematician might have resorted to drawing on theorems, or referring to diagrams, while the basket maker might say "If I can make it, then it must be true," but all were producing kinds of evidence.

Conclusion

This article illustrates the great value of skilled textile-making practices, such as basketry, being conducted alongside and in collaboration with mathematics. It illustrates how the abstract and the concrete, as well as the theoretical and the practical, are best understood as aspects of one another, and how complex spatial ideas can be explored and inspired through one activity such as basketry.

Alongside this, the article argues how important practical textile-making skills such as basketry are for the development of innovative pathways in human cognition. Both textile practitioners and mathematicians can use the same activity to explore patterns and exceptions as ways to help understand the similar, yet converging, processes of mathematics and textile making. These modes of inquiry are set within histories of practice and exploration, often using techniques in quite an *ad hoc* manner. What is important is that practitioners from these disciplines communicate so that dexterous hand skills continue to be valued as a significant feature of the generation of idea—as much as thinking and imagining are valued as aspects of practice.

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References

Arnold, Denise, and Elvira Espejo

2015 *The Andean Science of Weaving: Structures and Techniques of Warp-faced Weaves.* Thames & Hudson, London.

Ascher, Marcia, and Robert Ascher

1986 Ethnomathematics, *History of Science*, vol. 24, no. 2, June, pp. 125–44. SAGE Publications, Thousand Oaks.

1981 *The Code of the Quipu: A Study in Media, Mathematics and Culture.* University of Michigan Press, Ann Arbor.

Ascher, Marcia

2004 *Mathematics Elsewhere: An Exploration of Ideas Across Cultures.* Princeton University Press, Princeton.

Ayres, Phil., Alison Grace Martin, and Mateusz Zwierzycki

ms. *Beyond the Basket Case: A Principled Approach to the Modelling of Kagome Weave Patterns for the Fabrication of Interlaced Lattice Structures Using Straight Strips*, paper presented at AAG 2018: Advances in Architectural Geometry 2018, pp. 72-93. Edited by Lars Hesselgren, Axel Kilian, Samar Malek, Karl-Gunnar Olsson, Olga Sorkine-Hornung, and Christopher John Kenneth Williams. Gothenburg, 2018.

Barber, Elizabeth Wayland

1994 *Women's Work: The First 20,000 Years.* W. W. Norton & Company, New York and London.

Bléhaut, Jean-Francois

1994 *Iban Baskets.* Sarawak Literary Society, Kuala Lumpur.

Bunn, Stephanie

ms. Field notes, 2020.

Constantine, Mildred, and Jack Lenor Larsen

1972 *Beyond Craft: The Art Fabric.* Van Nostrand Reinhold, New York.

Deacon, A. Bernard, and Camilla H. Wedgwood

1934 Geometrical Drawings from Malekula and Other Islands of the New Hebrides, *Journal of the Royal Anthropological Institute of Great Britain and Ireland*, vol. 64, January–June, pp. 129–75. Royal Anthropological Institute of Great Britain and Ireland, London.

Dewey, John

1997 *Experience and Education.* Originally published in 1938. Simon & Schuster, New York.

1934 *Art as Experience.* Minton, Balch and Company, New York.

Eastop, Dinah

2007 Playing with Haddon's String Figures, *Textile: The Journal of Cloth and Culture*, vol. 5, no. 2, pp. 190–205. Taylor and Francis, Milton Park.

Emery, Irene

1966 *The Primary Structures of Fabrics: An Illustrated Classification.* The Textile Museum, Washington, D.C.

Farrand, Livingston

1900 Basketry Designs of the Salish Indians, *Memoirs of the American Museum of Natural History*, vol. 2, pt. 5. Edited by Franz Boas. Publications of the Jesup North Pacific Expedition 1 (1898–1900), vol. 1, pt. 5. Order of the Trustees of the American Museum of Natural History, New York.

Fleming, Colin

1998 *Mack the Scottie from the Isle of Wight.* Isle of Wight: Stage and Screen Specialities, no. 12, PO369NR.

Forces in Translation

2020a My First Woven Skew Cube, *Forces in Translation.* Posted June 9, accessed March 2022. https://forcesintranslation.org/my-first-woven-skew-cube/.

2020b Cycloid Weaving, Spirals and a Few Knots–A Link to an Online Introduction, *Forces in Translation.* Posted July 8, accessed March 2022. https://forcesintranslation.org/cycloid-weaving-spirals-and-a-few-knots-a-link-to-an-online-introduction/.

Friedman, Michael

2018 Falling into Disuse: The Rise and Fall of Froebelian Mathematical Folding within British Kindergartens, *Paedagogica Historica*, vol. 54, pp. 1–24. Taylor & Francis, Milton Park.

Gell, Alfred

1998 *Art and Agency: An Anthropological Theory.* Clarendon Press, Oxford.

Gerdes, Paulus

2010 *Otthava: Making Baskets and Doing Geometry in the Makhuwa Culture in the Northeast of Mozambique.* Centre for Mozambiquan Studies and Ethnoscience, Maputo.

1999 *Geometry from Africa: Mathematical and Educational Explorations.* The Mathematical Association of America, Washington, D.C.

Harris, Mary

1997 *Common Threads: Women, Mathematics and Work.* Trentham Books, London.

Holmes, Oliver

2021 Dead Sea Scroll Fragments and 'World's Oldest Basket' Found in Desert Cave, *The Guardian*, posted March 16, 2021. https://www.theguardian.com/world/2021/mar/16/israeli-archeologists-find-new-dead-sea-scroll-fragments.

Ingold, Tim

2015 Whirl, *Veer Ecology*, pp. 421–33. Edited by Jeffrey Jerome Cohen and Lowell Duckert. University of Minnesota Press, Minneapolis.

2007 *Lines: A Brief History.* Routledge, London.

Jones, Geraldine

ms. Field notes, 2020.

Küchler, Susanne

2001 Why Knot? Towards a Theory of Art and Mathematics, *Beyond Aesthetics: Art and the Technologies of Enchantment*, pp. 57-78. Edited by Christopher Pinney and Nicholas Thomas. Routledge, London.

Lévi-Strauss, Claude

1966 *The Savage Mind.* Translated by George Weidenfield. University of Chicago Press, Chicago.

1963 *Structural Anthropology.* Volume 1. Translated by Claire Jacobson Brooke Grundfest Schoepf. Basic Books, New York.

Lipka, Jerry, Dora Andrew-Ihrke, David Koester, Victor Zinger, Melfried Olson, Evelyn Yanez, and Don Rubenstein

2015 Indigenous Knowledge Provides an Elegant Way to Teach the Foundations of Mathematics, *Proceedings of the 37th Annual Meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education*, pp. 2–18. Edited by Tonya Gau Bartell, Kristen N. Bieda, Ralph T. Putnam, Kenneth Bradfield, and Higinio Dominguez. Michigan State University, East Lansing.

Mackey, Carol

2002 The Continuing Khipu Traditions: Principles and Practices, *Narrative Threads: Accounting and Recounting in Andean Khipu*, pp. 320–47. Edited by Jeffrey Quilter and Gary Urton. Joe R. and Teresa Lozano Long Series in Latin American and Latino Art and Culture. University of Texas Press, Austin.

Malinowski, Bronislaw

1987 *Argonauts of the Western Pacific.* Routledge, London.

Marchand, Trevor H. J.

2018 Towards and Anthropology of Mathematizing, *Interdisciplinary Science Reviews*, vol. 43, no. 3–4, pp. 295–316. Taylor & Francis, Milton Park.

Mason, Otis T.

1895 *The Origins of Invention: A Study of Industry Among Primitive Peoples.* The Walter Scott Publishing Co. and Charles Scribner's Sons, London and New York.

McKenzie, Robyn

2011 *The String Figures of Yirrkala: Examination of a Legacy. Exploring the Legacy on the 1948 Arnhem Land Expedition.* Edited by Martin Thomas and Margot Neale. Australian National University Press, Canberra.

Mellaart, James

1966 Excavations at Çatal Hüyük, 1965: Fourth Preliminary Report, *Anatolian Studies*, vol. 16, pp. 165–91. British Institute at Ankara, Ankara.

Mimica, Jadran

1988 *Intimations of Infinity.* Berg Publishers, Oxford.

Parsons, Gregory, and Philip Hughes

2022 *Alison Morton: Weaver.* Exhibition Catalogue. Theo Moorman Trust for Weavers and Ruthin Craft Centre, Ruthin.

Rossbach, Ed

1976 *The New Basketry.* Van Nostrand Reinhold, New York.

1973 *Baskets as Textile Art.* Van Nostrand Reinhold, New York.

Taimiņa, Daina

2018 *Crocheting Adventures on Hyperbolic Planes: Tactile Mathematics, Art and Craft for All to Explore.* Second Edition. Originally published in 2009 CRC Press, Boca Raton, London, and New York.

Tarnai, Tibor

n.d. Baskets. Published by Department of Structural Mechanics, Budapest University of Technology and Economics, Budapest, accessed September 18, 2021. me.bme.hu/sites/default/files/page/Baskets.pdf.

Urton, Gary

1997 *The Social Life of Numbers: A Quechua Ontology of Numbers and Philosophy of Arithmetic.* University of Texas Press, Austin.

Vandendriessche, Eric

2014 W. W. Rouse Ball and the Mathematics of String Figures. *Historia Mathematica* 41, no. 4, pp. 438–62. Elsevier, Amsterdam.

Verran, Helen

2001 *Science and an African Logic.* University of Chicago Press, Chicago.

Wood, Felicity

2007 Exploring Cubes Woven on the Skew. Published by The Bridges Organization, accessed September 18, 2021. https://archive.bridgesmathart.org/2007/bridges2007-441.pdf.