



## To Quilt is to Math: Investigating the Breadth and Depth of Mathematics in Fiber Crafts

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**Abstract:** This study investigates connections between fabric crafts and the breadth and depth of mathematics involved in pursuing the crafts with a particular focus on quilting. The authors became participant observers in crafting circles, conducted 65 semi-structured interviews to investigate crafters' mathematical insights in their projects, and analyzed artifacts through close manual examination and photographs to deepen these insights. We ask the questions: (1) How do crafters observe the interplay between mathematics and the process of a craft? (2) How can crafters' products illuminate the breadth and depth of mathematics? The findings suggest that the different ways in which mathematics and craft intersect either bear the form of a craft-forward approach, as crafters produce patterns and explore it through changes in the patterns or in the form of a math-forward approach, in which crafting directly draws on mathematical concepts guiding the work toward the improved performance or modeling of math concepts.

### Introduction

Girls report lower levels of interest and perceived ability in mathematics in secondary and higher education contexts (Fredricks and Eccles, 2002; Else-Quest et al., 2010; Guo et al., 2015; Ganley and Lubienski, 2016) due in large part to a lack of sense of belonging to the field (Cheryan, Drury, Vichayapai, 2012) even when they perform on par with men (Good, Rattan, & Dweck, 2012). As such, body of research focuses on the sociocultural context of learning and of doing mathematics outside of school contexts. However, it is rife with tensions and dilemmas (Boaler, 2007). These tensions culminate in colonized hegemonic ways of learning math through gendered and racialized categories. For example, fabric crafts are not usually included as a viable option for the study of math in informal and formal structures, despite research that demonstrates integrating mathematics with crafts and designs helps learners form a personal and meaningful connection with mathematical concepts (Shaffer, 1997; Elliott & Bruckman, 2002). Textile crafts have also contributed to generating new mathematical knowledge, including the modeling of hyperbolic planes using crochet (Taimina, 2009; Wertheim, 2005). Yet, in mathematics learning contexts, fiber crafts have largely been overlooked and their intellectual merit is still to be explored.

To pursue epistemic diversity of learning and being, it is necessary to recognize that crafting circles present opportunities to do mathematics within a diverse range of contexts (e.g., seeing domain concepts within fiber crafts) as well as recognizing and valuing action within these contexts as a form of mathematical doing that could lead to mathematical insights that are different from but not less important than traditional forms of mathematics. Our research interrogates the extent to which the culture of crafting can produce the learning conditions of Papert's (1980; 1993) Mathland to inform our understanding of the disconnect between mathematics as taught in school and everyday mathematics. The land metaphor within the term Mathland refers to the possibility of learning a language associated with a particular geographic region. Thinking of mathematics as a land where things are done in a particular way invites the possibility that there can be multiple languages and, by extension, multiple lands of mathematics. Additional Mathland-inspired principles have shaped efforts that seek to promote deep mathematical engagement. Earlier efforts to instill mathematics learning into craft have leaned heavily on technological interventions to make the mathematical principles of crafting salient to the learner. However, the larger work to which this paper contributes argues that crafting in itself is a technology that privileges patterned mathematical engagement and is supported by a social structure and broader crafting culture that rests on deep historical roots (Peppler, Keune, Thompson, 2020). In this paper, we analyze the mathematical concepts crafters use in their projects and how they form mathematical connections with their craft. To this end, we asked: (1) How do crafters observe the interplay of math and craft? (2) How can crafters' products illuminate the breadth and depth of mathematics?

To answer these questions, we draw on our ethnographic data that includes observational notes, semi-structured interviews with 65 crafters, and analysis of artifacts created by our participants. Crafters predominantly talked about mathematical engagement through craft terms (e.g., describing the pattern and arrangement of units into the overall pattern). They worked within an understanding of the process they were participating in and in

pursuit of the project they wanted to create. For instance, while crafters may not have explicitly mentioned interlocking tessellations by name as part of their math/craft insights, they were able to intricate shapes which required the elegant application of the principles of translation, rotation, and mirroring while working on the structure of their pieces, including in the seam lines, sewing order, and assembly. This study provided us with an understanding that craft is a promising context for creating Mathland which can serve as initial starting points about the processes through which engagement with math could be supported through crafting.

## Background

Giving learners powerful tools for creative expression by designing personally meaningful projects and sharing them with others is a central tenet of constructionist approaches to learning (Papert 1980;1992). Papert's constructionist approach draws on cognitivist and sociocultural perspectives by considering how a range of socio-material contexts support cognitive possibilities (e.g., domain learning) through ways of doing that are characteristic of the material context (Holbert, Berland, & Kafai, 2021). Crafting is a learning culture organized around the production of new artifacts and connecting with others in the process. Crafting promotes ties to one's cultural heritage, shaping learning and participation in ways specific to regional crafting traditions. Studies show that people engaging in fiber crafts apply mathematical ideas, but the nature of their engagement is distinct from traditional mathematics (Uttamchandani & Pepler, 2018.; Thompson, 2022; Keune, 2022; Pepler, Keune, Thompson, & Saxena, 2022). Mathlands within the constructionist tradition are learning environments in which rich doing of mathematics happens along the way of performing and practicing cultural practices that are deeply interconnected with mathematics. Papert (1980) describes Mathlands as microworlds where certain types of mathematical activities could develop with "particular ease" and the learner is involved in creative exploration of ideas. He compares children's learning of mathematics in a computer-based Mathland to learning their first language. This model acts against dissociated learning that takes place in schools that does not take into account activities such as mental and physical, resulting in epistemological alienation. Mathlands not only change the way we teach and learn mathematics, but also the way we situate learning in a cultural context.

## Methodology

Our longitudinal, multi-year ethnography as learner-practitioners positioned us both relationally and cognitively into crafting communities. Observing and learning with and from skilled crafters provided a multitude of opportunities to draw deep connections between aesthetically, intrinsically woven patterns, and mathematics. Our intention was to adapt the practices of the crafters and grasp crafting as a research process that includes creativity and experimentation to coproduce knowledge (Puwar & Sharma, 2012). These helped us to envision crafting circles as Mathlands that initiated mathematical conversations similar to learning a language (Papert, 1980), and their intergenerational and sociocultural features that have the potential to decolonize ways of learning, knowing, and doing. Participating in communities of practice and care that created artifacts for their loved ones or for social causes (e.g., Keune, Yankova, & Pepler, 2022) allowed us to understand the social and relational aspects of artifacts. For example, knitting covers for trees to spread love and care for nature, crafting donation quilts to distribute to community members in need, or making sweaters for the unhoused. The work as embedded ethnographers resulted in audio notes, detailed, field notes, and crafting photographs and videos of crafting processes. Data sources also included interviews. Using snowball sampling and contacts provided by crafters in the guilds, we reached out to potential interviewees, the majority of whom (90%, n=59) lived in urban areas. Of the 65 crafters we interviewed, 57 were White, three were Asian, four were Black, and one did not disclose their race; 60 identified as women, four as men, and one as non-binary. Their ages ranged between 20 and 72-years-old. The average length of the interviews was 59 minutes (minimum 19 minutes and maximum 166 minutes).

Following Carspecken's (1996) approach for semi-structured interviews, we analyzed our data in two phases. The first phase included demographic information (length of the interviews, age and generation, gender, occupation). In the second phase, we conducted segment analysis to divide interview transcripts into emerging themes followed by iterative thematic analysis. In addition, we analyzed artifacts and observational notes from our work as embedded ethnographers. The artifact analysis included talking about the projects with crafters and asking them to highlight mathematical actions and patterning within their crafts. Further analysis of artifacts and their photographs demonstrated mathematical insights beyond those articulated by the crafters. The following section describes how the crafters see mathematics in their craft and how we analyzed mathematical content in their finished projects leading to ways of reconstructing and transferring knowledge in new contexts through Mathlands.

## Findings

### How crafters observe the interplay of math and craft

Through an emergent and iterative thematic analysis of the summaries related to the larger theme of math in the craft, we identified that some crafters describe the interplay as math forward and some as craft forward. Thus, two themes emerged around *math shaping the craft* and *craft shaping the math*. We saw crafters as meaning that crafts shape math when they talked about crafts as drivers of mathematical insight and as math shaping the way crafts are designed and conceptualized. We found that 22% (n=14) of the interviewees considered craft as shaping math, nearly a similar number of crafters considered math as shaping crafts (23%, n=15), and over half of the interviewed crafters (54%, n=35) talked about their engagement as both craft shaping math and math shaping craft.

Crafters talked about craft as shaping math in five distinct ways: (1) Repetitive action to produce a pattern, (2) craft as materializing math, (3) craft as producing math, (4) craft as giving math purpose, and (5) craft as containing math. Most frequently, crafters mentioned patterns that produced math through repeating material actions (32%, n=21). For example, Julie talked about quilting: "Math is about recognizing patterns and coming up with formulas to predict those patterns in the future." This example suggests that the crafting practice produces a pattern that could not have been foreseen without the craft. Following the production of the pattern through craft, the pattern can be translated into symbolisms (i.e., "formulas") that help crafters reproduce the pattern.

Another way crafters articulated how crafts shaped math (15%, n=10) was in how craft materialized math and helped get a feeling for math by creating shapes. For example, Fiona (51 years old) spoke about sewing: "You can make changes (...) to make the fabric do something different. Individual stitches, that's where I see mathematical thinking constantly at work." It was the performance of the stitches that led to variations and changes in physical forms that supported Fiona and other crafters in getting a physical and material sense of a math concept. It was the production of the concepts and the possibility to vary through stitch combinations that clarified math through materialization. Others (12%, n=8) considered the way crafts shaped math as a longer-term production process in which crafting led to the slow discovery of math. Crafters (12%, n=8) also considered that crafts gave math a (personal) purpose, meaning that crafting gave them an opportunity to apply math in everyday life. Finally, 3% (n=2) said that craft contained math, meaning that math is always part of the craft but that crafters can choose whether and to what extent to actively engage with it. Across the board, for crafters who considered craft as shaping math, to engage with and know math with craft was neither tied to academic math understanding nor to an ability to point to academic math concepts in crafts. Math was part of crafts and lent itself to the discovery of math at their chosen speed.

Crafters talked about math as shaping craft in six ways: (1) math as improving craft, (2) math as externalized, (3) math as a prerequisite for craft, (4) absence of math hinders craft, (5) math as simplifying patterns, and (6) non-discrete math. These ways of math shaping craft are further explained below. Most commonly, crafters (35%, n=23) said that math improves their craft, meaning that applying math concepts enhances the quality and the range of the craft. For example, Veronica talked about sewing:

There is nothing like really understanding on an incredibly deep level how bad you are at spatial relations because you realize you just sewed the pocket inside out because you just don't understand shapes in 3-dimensional space.

As Veronica grew in her understanding of the concept of spatial relationships while learning her craft, over time she would become able to iterate fewer times and produce the kind of artifacts that she wanted to see more rapidly. In other words, here, improving math skills leads to improving craft skills.

Next, eight crafters (12%) said that math was externalized through crafting. This meant that crafters could use tools for mathematics that were made by others, including specific calculators. In these cases, crafters described how math intersected with craft and was required for craft but can be facilitated and externalized through specialized tools, for example, online quilting or weaving calculators or even tools invented by the crafters themselves (see also Keune, Yankova, & Pepler, 2021). Just as frequently, eight crafters (12%) said that math was a prerequisite for crafting. With this, they meant that knowing math was vital and necessary for performing a craft. It was not possible to perform the craft without knowing math. For instance, 33-year-old Susan said that "I do a lot of circle skirts so you have to solve for X like in the circumference equation to figure out because you need the inner circle to match the diameter of your waist and then the outer circle is the edge of the circle."

Less frequently, five crafters (8%) said that the absence of math hindered craft, five crafters (8%) said that math simplified patterns and made them more accessible, and one crafter (2%) said that math was non-discrete and that several concepts were in use at once. Interestingly, while crafters demonstrate several concepts at once in their craft and may name several mathematical insights as described above, here, they do not seem to often

name the non-discrete nature of their work, suggesting an inherent fluidity between mathematical concepts when translated to a materialized form.

Where the examples above show how crafters considered craft as shaping math and math as shaping crafts, the majority of crafters (54%,  $n=35$ ) did not exclusively consider either one of these perspectives in their practices. The perspectives most frequently came together and complemented one another. For instance, Phoebe (30 years old) sometimes led with math while sewing: “If you’re trying to decide on the dimensions of an object that you’re going to make and you look at an object that you like and then you measure the ratios of height to width.”

To produce an object, Phoebe measured and calculated the ratios to aid in the production process. Yet, as with other crafters who shared both perspectives, she also discusses instances when starting with the craft led to math discoveries:

I made the whole potholder but then I wanted to put quilting stitches in it in a rectangular array. I didn’t really plan it. I just started putting them at a spacing that seemed relevant but then I realized that it was a 7 x 7 array. That would have been 49 stitches and I decided to do 48 stitches instead.

Phoebe started to craft and then realized that the physical performance of the pattern could be formalized. The craft led her to discover the math through the production of the craft. This was representative of the other crafters whom we coded as both craft shaping math and math shaping crafts. Fluctuation between perspectives, leading with craft and leading with math, happened frequently, indicating that both perspectives played an equal role for these crafters.

These different ways math and craft came together showcase different ways mathematics can be explored through craft. This can come in the form of a craft-forward approach as crafters produce a pattern, explore changes in shapes through changes in these patterns, or talk about the purpose of mathematics in relation to a personally meaningful project. These observations can also happen in the form of a math-forward approach, in which the process of crafting directly draws on mathematics concepts toward the improved performance or the modeling of math concepts. A Mathland needs to incorporate these multiple entry points to ensure accessibility. Practicing math through crafts can start with math as well as with craft and one approach does not exclude the other.

### Illuminating the breadth and depth of the mathematics involved in craft projects

A breadth and depth of multiple mathematical concepts became visible in individual crafted projects. For example, Julia (56 years old) said “I’ve got to figure out the math ratio based on the 60-inch dimension of my fabric,” illustrating the use of *ratios and proportional* relationships. In Julia’s remark, she refers to the use of the size of the fabric to determine the proportional size of other design elements (see Figure 1). To create the quilt in the figure, the maker must determine the final desired length and width of the quilt (e.g., 60” x 60”). This square then is made up of an equal number of circles and half circles, with inwardly curved diamonds appearing within the circles. The shape formed between two adjacent diamonds is referred to as a leaf.

**Figure 1**  
*English Paper Piecing Quilt*



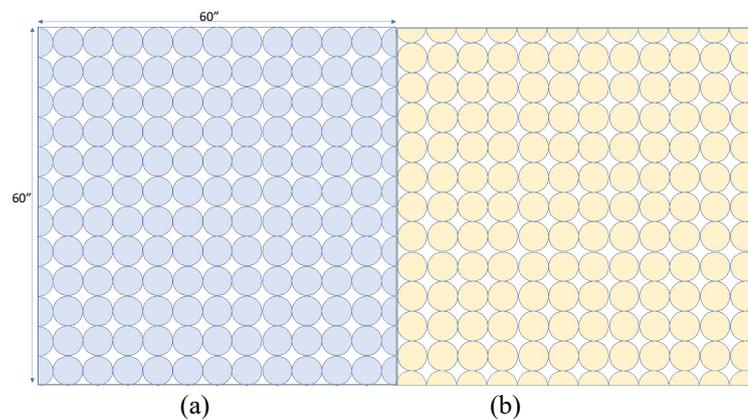
To determine how many of these shapes are necessary to complete a quilt, the maker must calculate the ratio of the diameter of one circle to the length of the full quilt. In Figure 1, it can be seen that 12 circles fit across the full length of the quilt. If the quilt is 60 inches long, the diameter of one of the circles must be 5 inches (i.e., 60" length/12 circles = 5" per circle). These circles are the primary units of the design. However, the mathematical task is not as simple as computing the size of the unit circles. The circles are made of two layers of fabric, and each has a different color or design, which leads to different designs on the two faces of the circle. The individual pieces of circular fabrics are then stitched together, while the display sides of both fabrics are in contact. Then, the stitched two-layered circles are turned inside out through a slit and are carefully cut along the edge of the inside square of one of the circular fabric layers. Turning them inside out results in a displayable circle of 5 inches in diameter. However, as the quilter cuts out the individual circular pieces, a seam allowance of 0.5 inches, which surrounds the circumference of each starting circular piece, must also be accounted for. Thus, without allowing for waste, the total starting fabric size needed is 66 inches by 66 inches, and the ratio of starting circle to the finished quilt edge is 0.092 (or 5.5" per circle /60" length = 0.092).

Note that the placement of the diamond shapes shown in Figure 1 also alternates, such that every other row ends with two half-circles at the quilt edge instead of twelve full circles all the way across. For the row that has 12 full circles, the dimension of the quilt is 60 inches due to the 12 full circles ( $12 \times 5 = 60$ ), while for the row that has 11 full circles and 2 half circles, so the quilt is still 60 inches ( $11 \times 5 + 2 \times 2.5 = 60$ ) across (see Figure 2).

Further examination of the pattern shown in Figure 1 indicates that the mathematical insights used by Julia incorporate geometric translations as well. The pattern could be visualized through overlapping the two sets of circle configurations as shown in Figure 2. The first set of circles are configured so that they make up twelve columns and twelve rows, with one column split into two columns of half circles that make up the first and last column (see Figure 2a). The diameter of each circle is 5 inches, and the periphery of the circles in each column touches those in the adjacent columns. Thus, the dimension of the sheet of circles is 60" x 60". The precision of these initial measurements has consequences for the quilt's aesthetics, and its feasibility. Every error in measurement will compound over time. The size and dimensions of the quilt as a whole will be irreparably altered if a mistake is made anywhere.

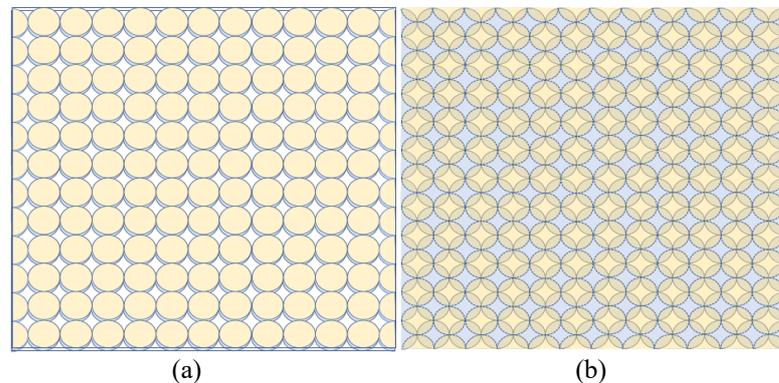
**Figure 2**

*Blue component with semicircles on the sides (a), yellow rotated component with semicircles on top and bottom*

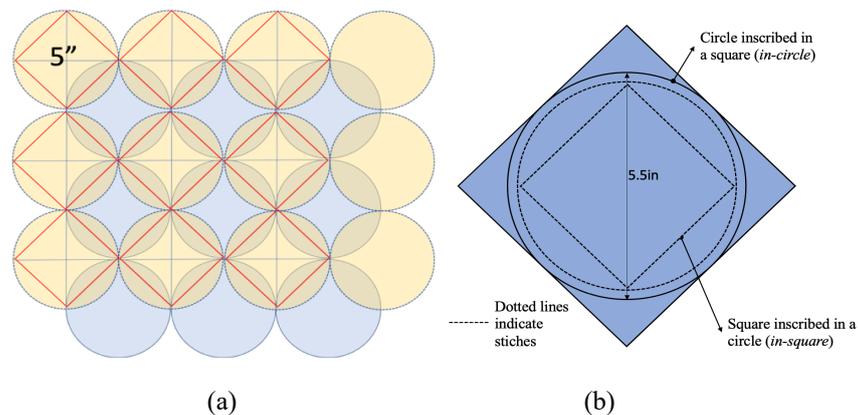


To begin this pattern, Julia arranged twelve yellow circles with a diameter of 5 inches to a sheet of blue circles, but rotated by 90 degrees. The second configuration, while still producing aggregate dimensions of 60 inches by 60 inches, shows the half circle row at the top and the bottom, demonstrating a geometric rotation (see Figure 2b). The rotation of one of the sheets produces a pattern when the two sheets in Figure 2 are superimposed (see Figure 3a). The blue and yellow overlapping components form leaves within circles, and the area not covered by the leaves in each circle has a diamond shape with curved edges. Thus, a leaf and a diamond are created in each of the yellow and blue circles (see Figure 3b).

**Figure 3**  
Overlap of two patterns without rotation (a), with rotation (b)



**Figure 4**  
Fabric planning for producing unit circles



The circular fabric pieces seem to be inscribed in square pieces of fabric. The circles thus inscribed are called *in-circles*; in these, the edge of the square has the same length as the diameter of the circle (see Figure 4). There are 12 such adjacent circles along a 60-inch quilt edge, so that each circle is 5 inches in diameter. Each of the *in-circles* is cut out from a 5-inch by 5-inch square piece of fabric (5.5 inches square with an allowance of a 0.25 seam on each side to form a two-layered circle). The finished circles with a 5-inch diameter are then attached through a seam along the circle's chord (the edge of the inner square) to produce leaves. Notably, the pre-planning calculations that go into the design of the quilt have deep ramifications for the crafter, in that the exacting manual tasks performed in each quadrant of the quilt are repeated several times and over a long duration of time. To understand the ramifications that inexactitude has for later labor on the quilt, crafters need to consider other aspects of the design, whether this be noticing interrelationships between shapes and space or planning ahead for other calculations (e.g., seam allowances and how they impact the overall dimensions of the quilt). As the crafter engages with the given product for a sustained period, the practice of iterative mathematical production allows deeper insights to emerge.

In sum, we observed crafters using proportional reasoning; properties of circles, incircles, and squares; spatial reasoning (mental rotation, spatial visualization, and spatial orientation); geometric translation; and aesthetic randomization of patterns. Producing quilt designs had the following salient components: First, the leaves in the quilt design are all of the same color, whereas the diamonds are of several colors. This requires choosing two fabric patterns in such a way that one side of the circles all have the same color/pattern (forming the leaves), whereas the reverse side has a diverse color and pattern (forming the diamonds). Second, the colors of the diamonds across the quilt, while they are to be nearly randomly distributed, should also be aesthetically pleasing. A mathematically random choice of arrangement must be supplemented by human judgment for aesthetics when selecting the placement of diamonds of different colors across the quilt. If all red diamonds are clustered together in one area of the quilt, even though this may be the output of a mathematically random

algorithm, it may not be pleasing. How a crafter selects aesthetically pleasing but seemingly random distributions calls for further research.

## Discussion

This work helped develop our understanding of crafters' relationship with mathematics, whether and how their relationship to academic mathematics compared to the mathematical insights that they reported using and experiencing in crafts, the types of mathematical concepts that crafters connected to crafting, how these intersect in action, and the breadth and depth of the mathematics involved in their finished projects. We gathered perspectives regarding whether and how craft is a promising context for mathematics learning. Crafters frequently fluctuated between explaining "math shapes craft" and "craft shapes math" demonstrating that both aspects play an equal and crucial role in their crafting practices. Our mathematical analysis of the English piecing quilt illuminates the impact of taking two-dimensional mathematics into three dimensions. Mathematical concepts of proportional reasoning, properties of circles, incircles, and squares, spatial reasoning (mental rotation, spatial visualization, and spatial orientation), geometrical translation, and aesthetic randomization of the patterns to include different colors were used in a variety of ways in various crafts and contexts. It is important to note that studies show that when trained on spatial skills, the subjects showed significant improvement in mathematics (Lowrie, Logan, & Ramful, 2017; Mix, Levine, Cheng, Stockton, & Bower, 2020). Crafts can be a context for training such skills. This line of inquiry resonates with what scholars have called for in "life-wide" STEM learning, in which attention is paid to learning experiences that connect to other areas of life, such as home and heritage, that transpire outside of the school day (Banks et al., 2007). A Mathland that is dedicated to pursuing crafts can provide a low floor for novices to enter with their mathematical skills and work their way through to make intricate quilts and reach a high elevation, disrupting mathematics learning as we see it in schools today. Such a Mathland can also provide wide walls to honor populations whose voices have been discounted and unheard in an effort to reify histories of knowledge hierarchies.

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